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TECHNICAL REPORT NO. 3-783

AN ANALYTICAL MODEL FOR PREDICTING  
CROSS-COUNTRY VEHICLE PERFORMANCE  
APPENDIX B: VEHICLE PERFORMANCE IN LATERAL AND  
LONGITUDINAL OBSTACLES (VEGETATION)  
VOLUME I: LATERAL OBSTACLES

by

C. A. Blackmon  
J. K. Stoll



December 1968

Sponsored by

Advanced Research Projects Agency

and

Directorate of Development and Engineering

U. S. Army Materiel Command

Service Agency

U. S. Army Materiel Command

Projects Nos. I-V-0-2500I-A-13I and I-V-0-2170I-046-02

Conducted by

U. S. Army Engineer Waterways Experiment Station

CORPS OF ENGINEERS

Vicksburg, Mississippi

ARMY-MRC VICKSBURG, MISS.

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## FOREWORD

The study reported herein was performed by the U. S. Army Engineer Waterways Experiment Station (WES) for the Office, Secretary of Defense (OSD), Advanced Research Projects Agency (ARPA), and is a portion of one task of the overall Mobility Environmental Research Study (MERS) sponsored by OSD/ARPA for which the WES was the prime contractor and the U. S. Army Materiel Command (AMC) was the service agent. The broad mission of Project MERS was to determine the effects of the various features of the physical environment on the performance of cross-country ground contact vehicles and to provide therefrom data that can be used to improve both the design and employment of such vehicles. A condition of the project was that the data be interpretable in terms of vehicle requirements for Southeast Asia. The funds employed for this study were allocated to WES through AMC under ARPA Order No. 400. Some funds for preparation and publication of this report were provided by the Directorate of Development and Engineering, AMC, under Department of the Army Project LT062109A131, "Military Evaluation of Geographic Areas," and Task-02 "Surface Mobility," of Project LT062103A046, "Trafficability and Mobility Research." The field work was performed during the period June 1964 to November 1965, under the general guidance and supervision of the MERS Branch of the WES, the staff element of WES responsible for the technical management and direction of the MERS program.

This appendix is one of seven to the report entitled An Analytical Model for Predicting Cross-Country Vehicle Performance. These appendixes are:

### A. Instrumentation of Test Vehicles

## FOREWORD

The study reported herein was performed by the U. S. Army Engineer Waterways Experiment Station (WES) for the Office, Secretary of Defense (OSD), Advanced Research Projects Agency (ARPA), and is a portion of one task of the overall Mobility Environmental Research Study (MERS) sponsored by OSD/ARPA for which the WES was the prime contractor and the U. S. Army Materiel Command (AMC) was the service agent. The broad mission of Project MERS was to determine the effects of the various features of the physical environment on the performance of cross-country ground contact vehicles and to provide therefrom data that can be used to improve both the design and employment of such vehicles. A condition of the project was that the data be interpretable in terms of vehicle requirements for Southeast Asia. The funds employed for this study were allocated to WES through AMC under ARPA Order No. 400. Some funds for preparation and publication of this report were provided by the Directorate of Development and Engineering, AMC, under Department of the Army Project LT062109A131, "Military Evaluation of Geographic Areas," and Task-02 "Surface Mobility," of Project LT062103A046, "Trafficability and Mobility Research." The field work was performed during the period June 1964 to November 1965, under the general guidance and supervision of the MERS Branch of the WES, the staff element of WES responsible for the technical management and direction of the MERS program.

This appendix is one of seven to the report entitled An Analytical Model for Predicting Cross-Country Vehicle Performance. These appendixes are:

### A. Instrumentation of Test Vehicles

- B. Vehicle Performance in Lateral and Longitudinal Obstacles (Vegetation)
  - Volume I: Lateral Obstacles
  - Volume II: Longitudinal Obstacles
- C. Vehicle Performance in Vertical Obstacles (Surface Geometry)
- D. Performance of Amphibious Vehicles in the Water-Land Interface (Hydrologic Geometry)
- E. Quantification of the Screening Effects of Vegetation on Driver's Vision and Vehicle Speed
- F. Soil-Vehicle Relations on Soft Clay Soils (Surface Composition)
- G. Application of Analytical Model to United States and Thailand Terrains

The study was conducted by personnel of the Area Evaluation Branch, Mobility and Environmental (M&E) Division, under the general supervision of Mr. W. J. Turnbull, Technical Assistant for Soils and Environmental Engineering; Mr. W. G. Shockley, Chief, M&E Division; Mr. S. J. Knight, Assistant Chief, M&E Division; Mr. A. A. Rula, Chief, MEES Branch; Mr. Warren E. Grabau, Chief, Area Evaluation Branch; and Mr. Jack F. Stoll, Chief, Field Test Section, who was in direct charge of all phases of the study. Personnel of WES technical support elements provided major assistance in the field test program. Analysis of the data was performed by Mr. C. A. Blackmon. This report was written by Messrs. Blackmon and Stoll.

Directors of the WES during this study and preparation of this report were COL Alex G. Sutton, Jr., CE; COL John R. Oswalt, Jr., CE; and COL Levi A. Brown, CE. Technical Director was Mr. J. B. Tiffany.

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## NOTATION

|           |  |
|-----------|--|
| $A$       | Area of structural cell, $\text{ft}^2$   |
| $\bar{A}$ | Mean area per stem, $\text{ft}^2$  |
| $A_d$     | Area denied, $\text{ft}^2$   |
| $C$       | Cohesion, psi  |
| $d_a$     | Diameter of mean area per stem, ft   |
| $d_o$     | Diameter of circle whose area is equivalent to the area occupied by an obstacle, in. |
| $d_s$     | Diameter of stem, in.  |
| $D_c$     | Diameter of structural cell, ft  |
| $D_p$     | Actual path length of test run, ft   |
| $D_s$     | Straight-line distance from beginning to end of test run, ft                         |
| $L_m$     | Length of major axis of elongated obstacle, ft                                       |
| $s_e$     | Mean obstacle spacing, ft  |
| $t$       | Total time of test, sec  |
| $w$       | Width of vehicle, ft   |
| $\phi$    | Friction angle, deg  |
| $\Omega$  | Angle at which vehicle approaches elongated obstacle, deg                            |

## CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

| <u>Multiply</u>        | <u>By</u>  | <u>To Obtain</u>                |
|------------------------|------------|---------------------------------|
| inches                 | 2.54       | centimeters                     |
| feet                   | 0.3048     | meters                          |
| square feet            | 0.092903   | square meters                   |
| miles                  | 1.609344   | kilometers                      |
| pounds                 | 0.45359237 | kilograms                       |
| pounds per square inch | 0.070307   | kilograms per square centimeter |
| miles per hour         | 1.609344   | kilometers per hour             |
| pounds per cubic foot  | 16.0185    | kilograms per cubic meter       |
| short tons (2000 lb)   | 907.185    | kilograms                       |

## SUMMARY

A total of 95 lateral obstacle tests were conducted with two tracked and three wheeled vehicles at the NASA Marshall Space Flight Center, Miss., and Eglin Air Force Base, Fla. The principal conclusions from these tests were that (a) vehicle performance in terms of speed made good in an array of vegetation assemblages can be correlated with the density of vegetation assemblages expressed as mean obstacle spacing, (b) the minimum obstacle spacing required to permit movement of a vehicle can be computed from vehicle width, and (c) the speed made good a vehicle can achieve when maneuvering in lateral obstacles is significantly affected by the slope of the terrain.

Methods of determining mean obstacle spacing from structural cell diameter and percent area denied from stem diameters of trees, vehicle width, and structural cell diameter are shown. A method of determining percent area denied by logs, mounds, and other obstacles is suggested.

AN ANALYTICAL MODEL FOR PREDICTING  
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APPENDIX B: VEHICLE PERFORMANCE IN LATERAL  
AND LONGITUDINAL OBSTACLES (VEGETATION)

VOLUME I: LATERAL OBSTACLES

PART I: INTRODUCTION

Background

1. The main text of this report describes the development of an analytical model for predicting the cross-country performance of a vehicle. The model was based on an energy concept within the framework of classical mechanics that requires cause-and-effect relations be established between discrete terrain factors and vehicle response. This volume of Appendix B deals with the effects of a single terrain factor--lateral obstacles. The term "obstacles" in general refers to all features of the terrain, except soil, that are inhibitory to vehicle mobility. The obstacle-effects spectrum on vehicle mobility ranges from complete immobilization to minor speed reduction. For the purpose of the overall study, obstacles were categorized according to the direction of motion forced upon a vehicle negotiating the obstacle, i.e. vertical, lateral, or longitudinal.

2. The lateral obstacle category includes trees, boulders, holes, mounds, etc., that the vehicle cannot or does not, through the operator's choice, override.

Purpose and Scope

3. This volume describes the lateral obstacle tests conducted during the period August 1964-April 1965. The general purpose of these tests was to obtain data relating characteristics of lateral obstacles to vehicle performance in terms suitable for use in developing that portion of the analytical model for cross-country performance. The specific purposes were to determine (a) if vehicle performance, in terms of speed made good, could

be related to the mean spacing of trees as defined by the structural cell,\* and (b) what other characteristics of vegetation and what vehicle characteristics are suitable for the development of empirical performance relations.

4. Ninety-five tests were conducted with five vehicles in fairly homogeneous forests at eight sites in two general areas. The diameters of the trees ranged from about 4 to 10 in.\*\* The lowest branches of the trees were sufficiently high so as not to impede the vehicles. The sizes and distribution of the trees at each site were determined, and the time required for each traverse (traverses ranged from less than 100 to about 900 ft) was recorded.

5. Although only vegetation was tested, the application of the principles and analysis techniques to other types of lateral obstacles is discussed in this report.

---

\* The structural cell concept with its derivatives, mean tree spacing, nearest neighbor distance, etc., has been explored with some intensity by the U. S. Army Engineer Waterways Experiment Station. The concept is described in "Quantitative Physiognomic Analysis of the Vegetation of the Florida Everglades," by H. L. Mills, Contract Report No. 3-72, 1963, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.; prepared by Marshall University, Huntington, W. Va.

\*\* A table of factors for converting British units of measurement to metric units is presented on page xi.

## PART II: TEST PROGRAMS

### Location and Description of Test Areas

6. The tests reported herein were conducted at two locations in the southeastern United States: NASA Marshall Space Flight Center, near Picayune, Miss., and Eglin Air Force Base (EAFB), Fla. (fig. B1). Descriptions of test sites at the time the tests were conducted are given in the following paragraphs.

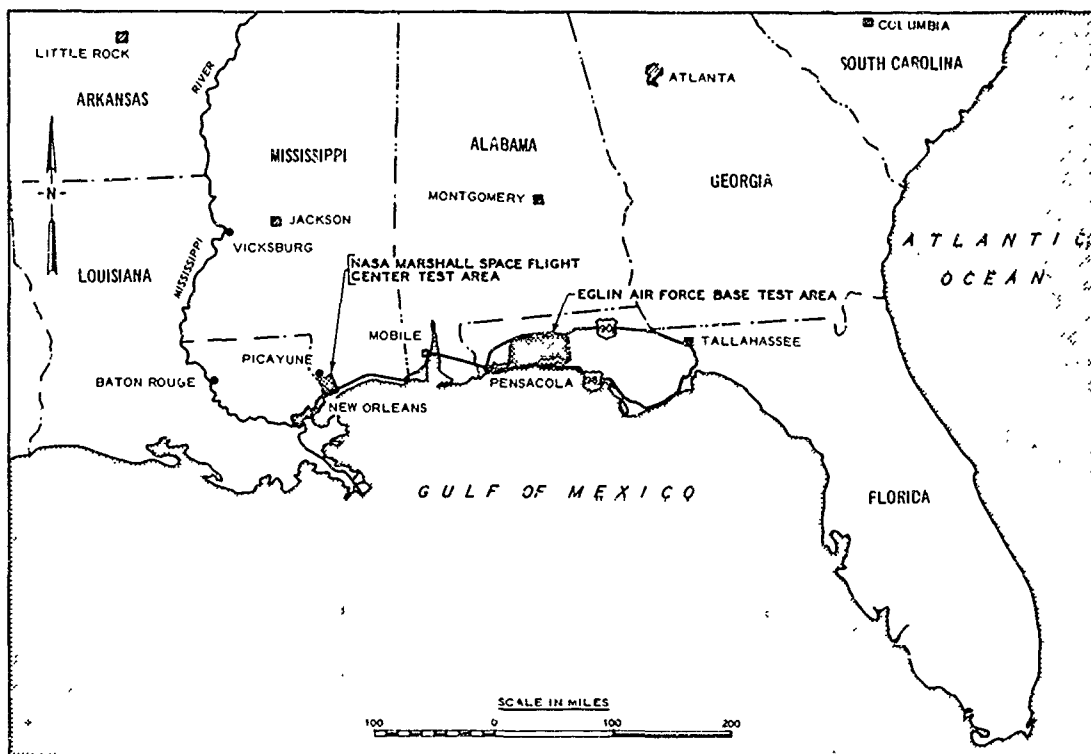


Fig. B1. Vicinity map, NASA Marshall Space Flight Center and Eglin Air Force Base test areas

### NASA Marshall Space Flight Center

7. The four sites at NASA Marshall Space Flight Center were identified as NASA1, NASA2, NASA3, and NASA4 (fig. B2). The sites were approximately 500 ft long and 250 ft wide and very nearly level (less than 0.5 percent slope along each test run). Trees at the sites were coniferous, or coniferous and hardwood mixed. Ground cover varied from pine straw to small bushes (fig. B3). Soils in the area were classified as ML, CL-ML,

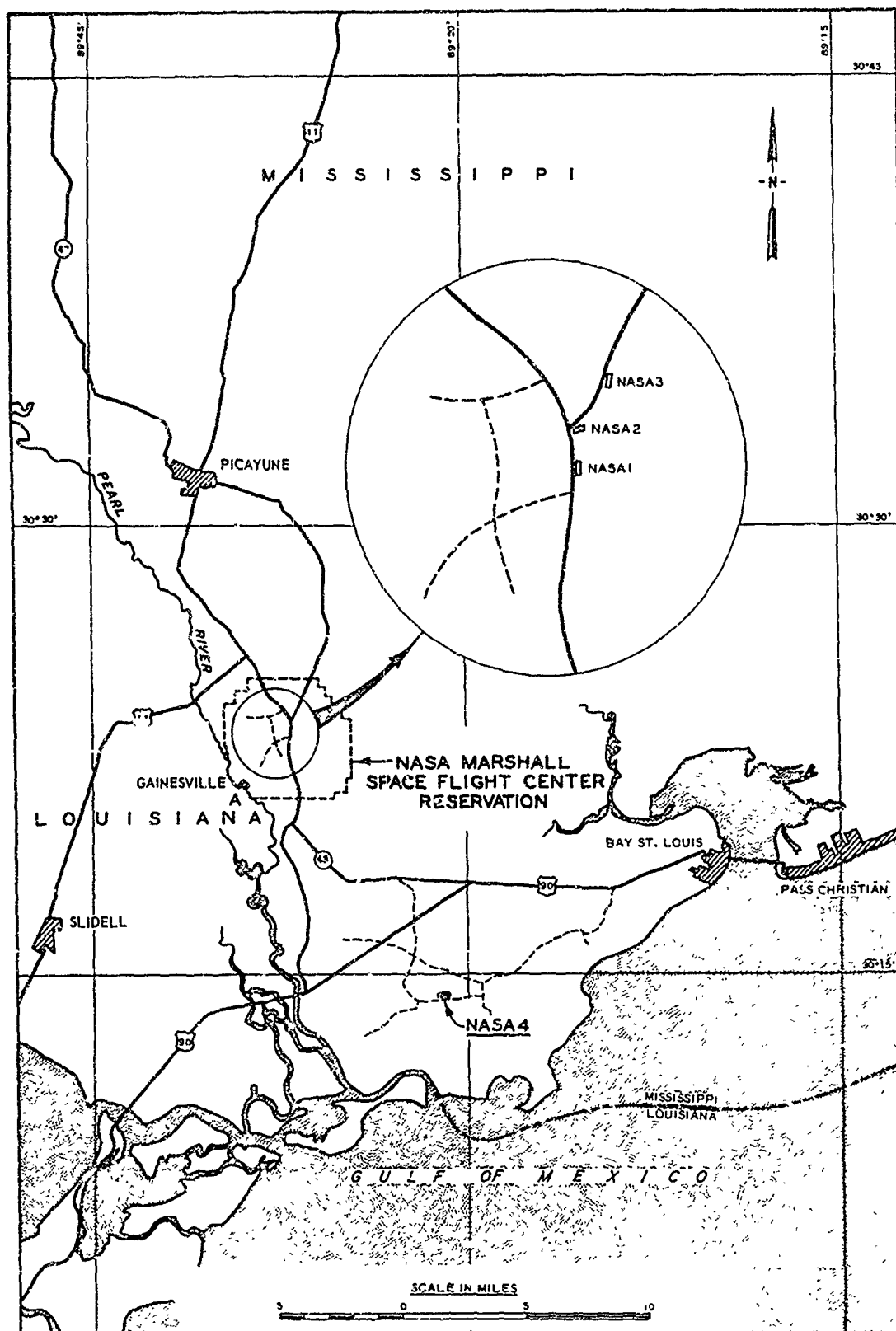
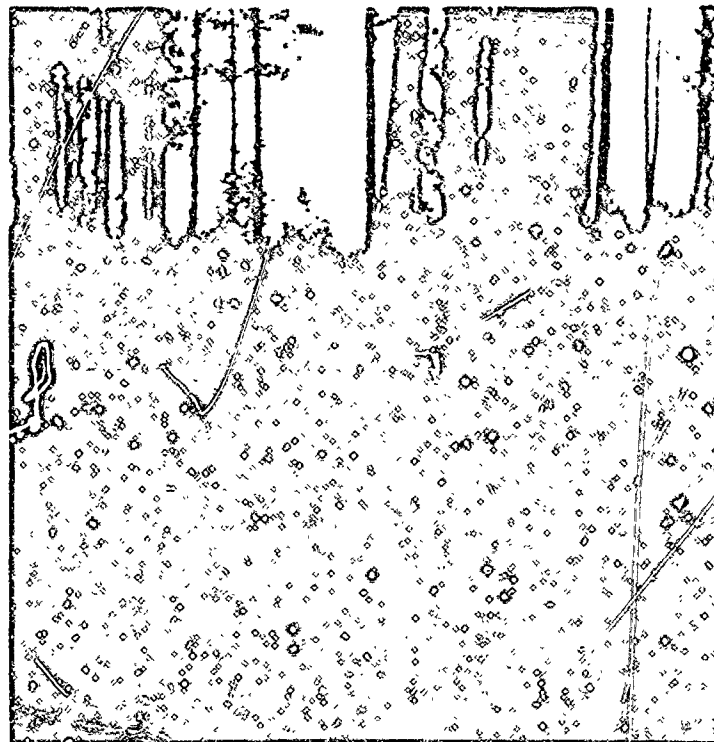
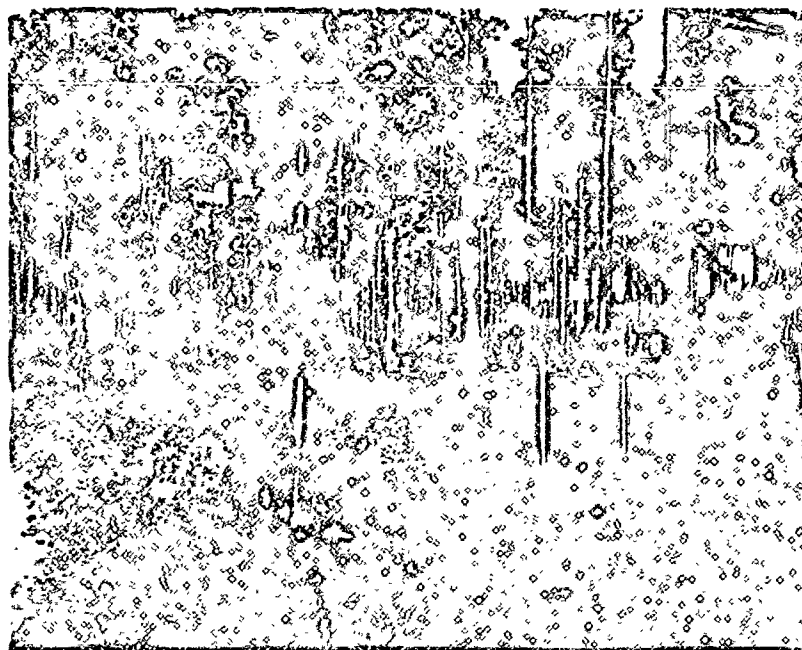


Fig. B2. Location of test sites, NASA Marshall Space Flight Center test area



a. Pine-straw-covered surface



b. Brush-covered surface

Fig. B3. Surface covers at NASA Marshall Space Flight Center test area



and SM, according to the Unified Soil Classification System (USCS). Average cone index in the 0- to 6-in. layer ranged from 55 to 316 and in the 6- to 12-in. layer from 67 to 375. A few stumps and stump holes were scattered over the area, and these were marked with stakes and considered as lateral obstacles.

#### Eglin Air Force Base

8. The four sites at Eglin were identified as E1, E2, E3, and E4 (fig. B4). Each site was approximately 500 ft long and 250 ft wide. The ground surface was sloping at all sites in the EAFB area; slopes ranged from 0.5 to 12.6 percent (fig. B5). Trees at the sites were coniferous, or coniferous and hardwood mixed (fig. B6). Small trees and all large bushes were cleared from the sites leaving a surface cover of pine straw and small brush. Soils in the EAFB area were classified as SP according to the USCS. Average cone index in the 0- to 6-in. layer ranged from 54 to 172, in the 6- to 12-in. layer from 70 to 351. The few stumps and stump holes scattered over the area were marked with stakes and considered as lateral obstacles.

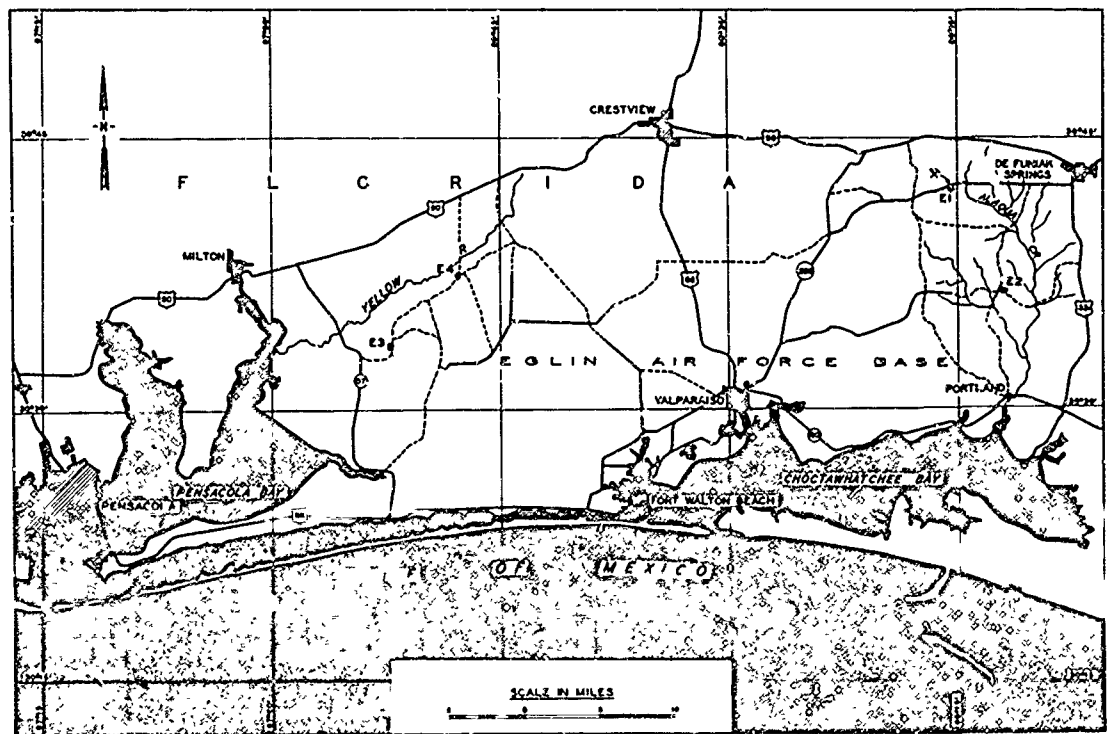
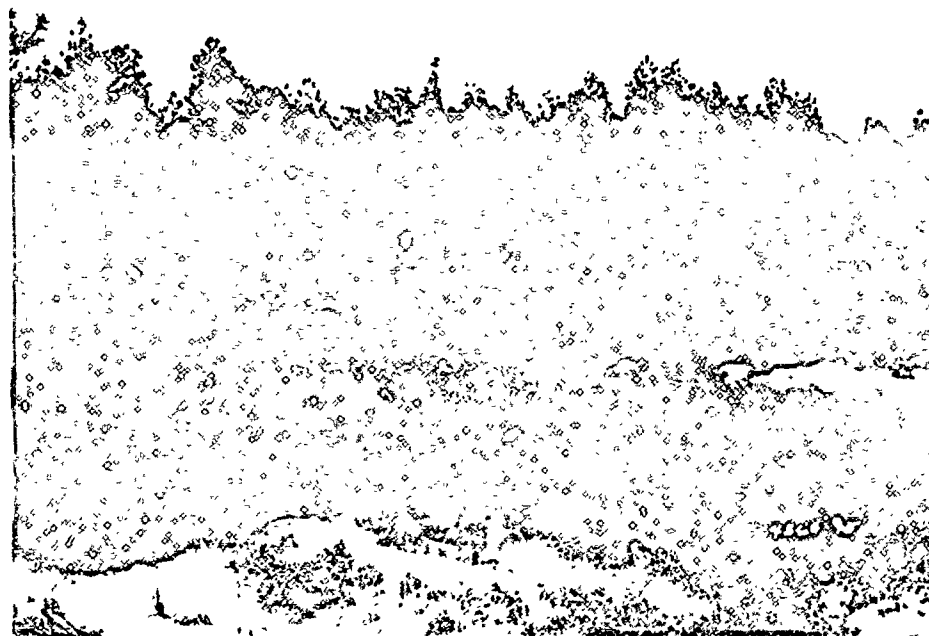


Fig. B4. Location of test sites, Eglin Air Force Base test area

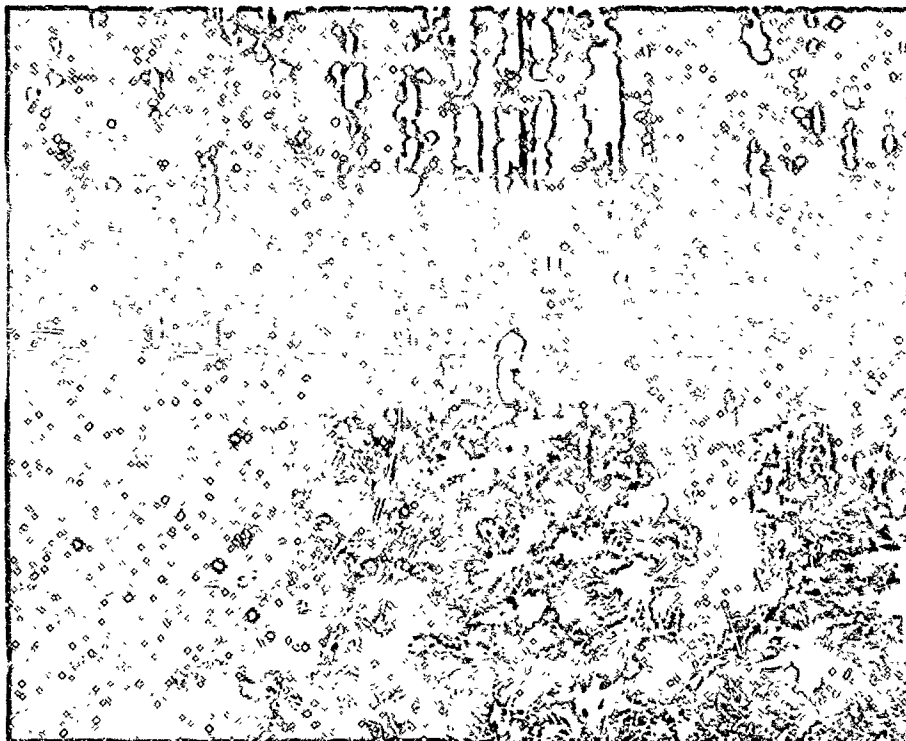


a. Gentle slopes



b. Steeper slopes

Fig. B5. Ground surface slopes at EAFB test area



a. Coniferous trees

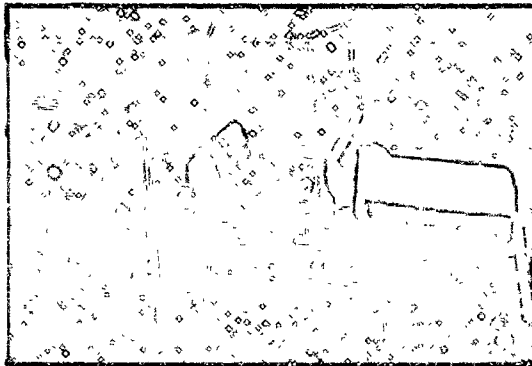


b. Coniferous and hardwood trees

Fig. B6. Trees at EAFB test area

### Vehicles Used

9. Three wheeled vehicles--the M151 1/4-ton utility truck, the M37 3/4-ton cargo truck, and the M35A1 2-1/2-ton cargo truck--and two tracked vehicles--the M29C amphibious cargo carrier and the M113 armored personnel carrier--were used in these tests (see figs. B7 and B8). Pertinent



a. M151 1/4-ton utility truck



b. M37 3/4-ton cargo truck

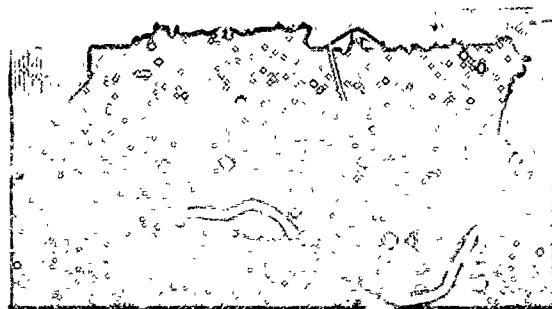
c. M35A1 2-1/2-ton cargo truck



Fig. B7. Wheeled vehicles used in test program



a. M29C amphibious cargo carrier



b. M113 armored personnel carrier

Fig. B8. Tracked vehicles used in test program

physical characteristics of the vehicles are given in table B1.

10. All of the vehicles, with the exception of the M151, were equipped with fairly elaborate measuring and recording systems.\*

#### Tests Conducted

11. The tests sought answers to the questions "How fast can these vehicles go through a stand of trees?" and "To what physical characteristics of the vehicle and of the tree stand can this speed be related?" The testing approach was straightforward; tree stands of reasonably uniform density were located and the vehicles were maneuvered through them at the fastest speeds possible commensurate with the driver's ability. The mean structural cell diameter (an inverse index of tree density), the mean stem diameters, and the number of tests with each vehicle at each site were as follows:

| Location | Mean<br>Structural<br>Cell Diam<br>ft | Main<br>Stem<br>Diam<br>in. | No. of Tests |     |       |      |      | Total |
|----------|---------------------------------------|-----------------------------|--------------|-----|-------|------|------|-------|
|          |                                       |                             | M151         | M37 | M35A1 | M29C | M113 |       |
| NASA2    | 34                                    | 4.4                         | 1            | 3   | 0     | 2    | 0    | 6     |
| E2       | 48                                    | 8.1                         | 2            | 2   | 0     | 4    | 0    | 8     |
| E3       | 54                                    | 5.2                         | 3            | 3   | 2     | 5    | 0    | 13    |
| NASA2    | 62                                    | 8.6                         | 2            | 2   | 2     | 3    | 4    | 13    |
| E4       | 67                                    | 4.4                         | 3            | 3   | 3     | 5    | 5    | 19    |
| E1       | 70                                    | 6.2                         | 4            | 3   | 4     | 3    | 4    | 18    |
| NASA4    | 77                                    | 9.8                         | 0            | 2   | 0     | 2    | 2    | 6     |
| NASA1    | 132                                   | 6.5                         | 2            | 2   | 2     | 2    | 4    | 12    |
| Total    |                                       |                             | 17           | 20  | 13    | 26   | 19   | 95    |

\* These systems are described in detail in "An Analytical Model for Predicting Cross-Country Vehicle Performance; Appendix A: Instrumentation of Test Vehicles," by B. O. Benn and M. Keown, Technical Report No. 3-783, July 1967, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

## Test Procedure and Performance Data

12. Approach lanes permitted the driver to enter the test site at the desired speed. He continued through the site in the most expeditious manner while avoiding all of the trees. A separate point of entry was selected for each test within a given site so that tests would be over different paths. Only one driver was used in the test program.

13. Instrumentation installed on the test vehicles (except the M151 1/4-ton truck) recorded continuous measurements of time, drive shaft revolutions, wheel or track rotational velocity, and drive line torque. In addition, for some tests vertical and longitudinal accelerations were measured and recorded. Event marks on an oscillogram indicated the beginning and end of the test and correlated the record with ground reference points. An example of an oscillogram record is shown in fig. B9. For the M151 1/4-ton truck, time from start to end of the test

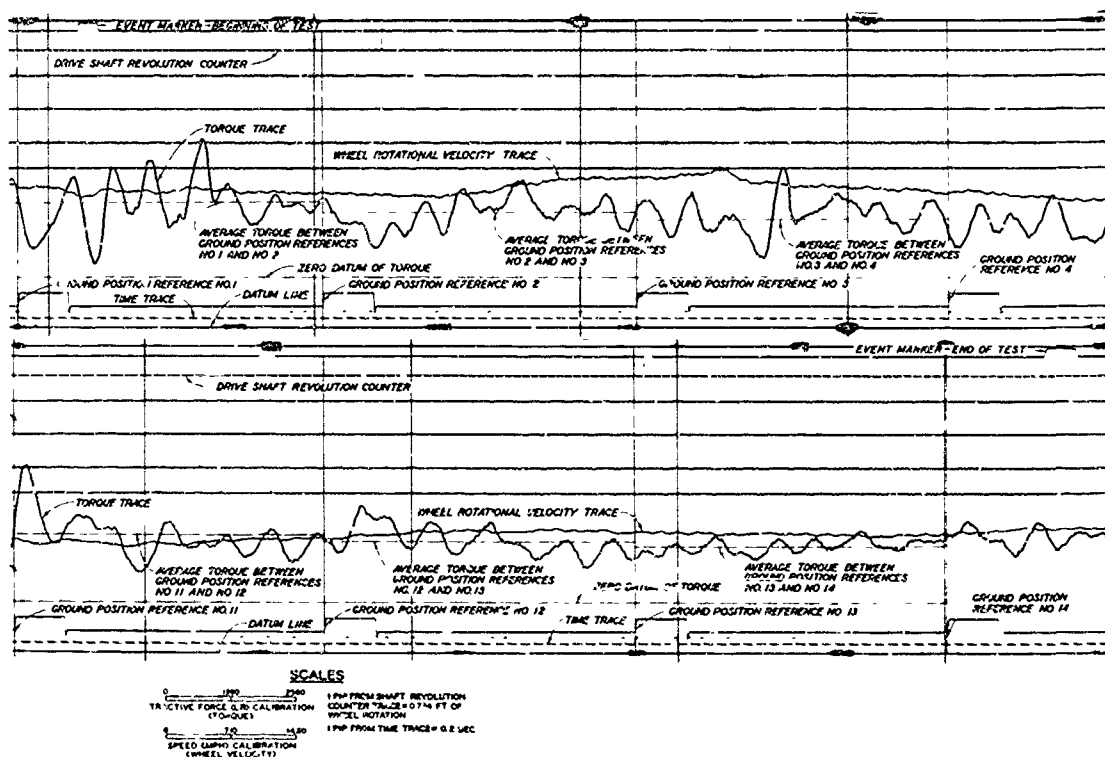


Fig. B9. Oscillogram record, test 281, M37 3/4-ton cargo truck

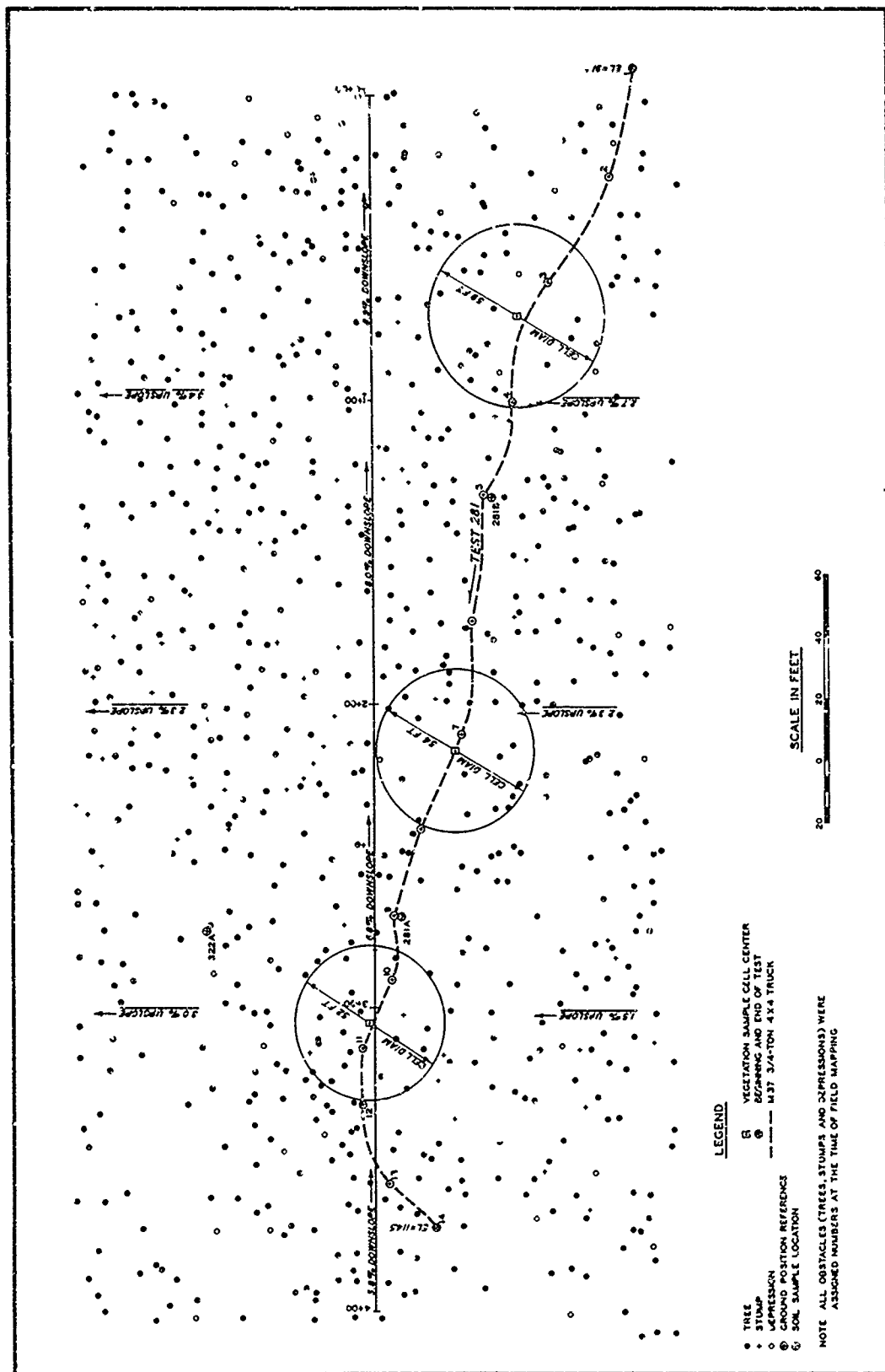


Fig. B10. Planimetric map of lateral obstacles, test site E2

run was measured by a stopwatch. A stopwatch was also utilized on the other vehicle tests in case the oscillograph recorder malfunctioned and to permit a quick estimate of speed immediately after each test. Appropriate data from the tests are summarized in table B2.

#### The Planimetric Map

14. To portray the tests graphically and for convenience in analysis of test results, a planimetric map was prepared of each test site, showing the location of each tree and other obstacles in the test site and the average slope perpendicular and parallel to the center line of the site. Following each test, the path of the vehicle was plotted on the map using a plane table and alidade in the field. The relative elevation of the ground was determined for the beginning and ending points of the test and all ground reference points along the path. The actual distance traveled by the vehicle and the straight-line distance from beginning to end of the test were measured on the planimetric map. At least three vegetation structural cells were constructed on the map along the path of the vehicle. An example of a planimetric map and structural cells is shown in fig. B10. Table B2 includes data obtained from the planimetric maps.

#### Soil Data Obtained

15. Generally two soil sampling locations were selected along the path of each test. A summary of the data obtained in the sampling is given in table B2.

##### Cone index

16. Ten cone index profiles were measured at each soil sampling location. Measurements were made at the surface and at 3-in. vertical increments to a depth of 18 in.

##### Rating cone index

17. Occasional remolding index measurements, which indicate the direction and magnitude of the change in strength of soil that will obtain under repetitive traffic, were made for the 0- to 6-in. and 6- to 12-in.



soil layers. The average cone index for a given soil layer was multiplied by the remolding index for that layer to obtain the rating cone index.

#### Surface shear measurements

18. Cohesion and frictional angle measurements were obtained with the Cohron sheargraph\* for rubber-to-litter, rubber-to-soil, and soil-to-soil conditions at most soil sample locations.

#### Moisture content

19. Average moisture content was usually determined from the 0- to 1-in., 0- to 6-in., and 6- to 12-in. soil layers.

#### Density

20. Samples for the determination of unit dry weight were secured at most locations for the 0- to 6-in. and 6- to 12-in. soil layers.

#### Bulk samples

21. Samples for classification of the soil according to the USCS were obtained from the 0- to 6-in. and 6- to 12-in. layers for each test.

#### Other Data Obtained

22. Other data obtained included the following: stem diameter at breast height, crown diameter, tree height, branching height, tree common name, photographs, and notes and observations.

---

\* "Operation Manual for the Cohron Sheargraph," July 1963, Wilson, Nuttall, Raimond, Engineers, Inc., Chestertown, Md.

### PART III: ANALYSIS OF DATA

23. The data collected in this test program are analyzed below under three headings: Speed-Spacing Relations; Speed-Area Denied Relations; Notes, Observations, and Other Data Considered. The conditions and assumptions upon which the analysis is based are described briefly in the following section.

#### Basis of Analysis

24. The nautical term "speed made good" was selected as the parameter to represent the vehicle performance in this study. Speed made good is defined as the straight-line distance from the beginning to the end of the test run divided by the time required for the vehicle to make the run. The increase in distance traveled as a result of maneuvering during the tests is expressed in terms of a path elongation ratio, i.e. the actual path length divided by the straight-line distance.

25. From a study of the results of the tests reported herein and the findings in other programs it was determined that the size of the structural cell was the characteristic that best described a vegetation assemblage and that would serve as a starting point from which to derive parameters that could be empirically correlated with vehicle performance. Two such parameters are considered in this report. The first is mean obstacle spacing and is nonvehicle dependent; the second is area denied and is both obstacle and vehicle dependent. For the latter vehicle width was selected as the most significant vehicle characteristic. The development of each of the parameters is discussed in the appropriate section.

26. For the analysis the tests were separated into two groups on the basis of USCS soil type. The two groups were (a) fine-grained soils and sands with fines, poorly drained (ML, CL-ML, and SM) and (b) coarse-grained soils (SP). The range of soil strength encountered by each vehicle in each soil group is shown in the following tabulation.

| Vehicle | Range of Average Cone Index<br>of ML, CL-ML, and SM Soils |                       | Range of Average Cone Index<br>of SP Soils |                       |
|---------|---|-----------------------|--|-----------------------|
|         | 0- to 6-in.<br>Layer                                      | 6- to 12-in.<br>Layer | 0- to 6-in.<br>Layer                       | 6- to 12-in.<br>Layer |
| M151    | 55-163  | 67-204                | 57-115                                     | 72-143                |
| M37     | 89-316  | 109-375               | 57-115                                     | 72-143                |
| M35A1   | 65-111  | 68-96                 | 54-172                                     | 76-351                |
| M29C    | 67-229  | 96-285                | 64-167                                     | 82-224                |
| M113    | 59-182  | 81-207                | 55-63                                      | 70-129                |

From the tabulation above it can be seen that tests were run on a wide range of soil strengths in each soil group. Despite this, there were not enough tests at a uniform spacing and a range of soil strengths to determine the influence of variation in soil strength. From discussions with the driver following each test, it appeared that generally he had been able to reach the speed he desired, that is, that he drove as fast as he thought safe. The observers agreed insofar as the tests in narrow obstacle spacings were concerned, but believed that the driver could have achieved a higher speed in the wider spacings had the soil been firmer. The data in table B2 indicate slip for some tests; and the effect of slip on the driver's confidence, resulting in his selection of a lower speed, might be easily hypothesized. In brief, it is believed that further testing is warranted to determine the degree of significance of soil strength on vehicle performance in lateral obstacles.

27. Other factors affecting vehicle performance in lateral obstacles are discussed in the section Notes, Observations, and Other Data Considered.

#### Speed-Spacing Relations

##### Mean obstacle spacing

28. Mean obstacle spacing may be considered as the first derivative of the structural cell. When the area of the structural cell is divided by the number\* of stems in the cell the result is the average or mean area

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\* In the structural cell concept, 20 stems comprise each structural cell. Lateral obstacles such as boulders, holes, mounds, etc., as well as trees are included in the stem count.

occupied by one stem. Considering this area as a circle with the stem at the center, the radius is the distance that is free before entering the mean area of another stem. Since the mean area per stem is equal for all stems in the cell, it follows that the mean distance or spacing between stems is equal to the diameter of the circle encompassing the mean area per stem. This diameter has been termed mean obstacle spacing. It should be noted that mean obstacle spacing approximates the difference between tree centers. Two equations to calculate mean obstacle spacing are derived below.

Equation Based  
on Diameter

$$\bar{A} = \frac{A}{20}$$

$$\frac{\pi d_a^2}{4} = \pi \frac{D_c^2}{20}$$

$$d_a^2 = \frac{D_c^2}{20}$$

$$d_a = 0.224 D_c$$

and by definition

$$d_a = s_e$$

where

Equation Based  
on Area

$$\bar{A} = \frac{A}{20}$$

$$\frac{\pi d_a^2}{4} = \frac{A}{20}$$

$$d_a^2 = \frac{4}{\pi} \frac{A}{20}$$

$$d_a = 0.252 \sqrt{A}$$

and by definition

$$d_a = s_e$$

$$A = \text{area of structural cell} = \frac{\pi D_c^2}{4}$$

$$\bar{A} = \text{mean area per stem} = \frac{\pi d_a^2}{4}$$

$D_c$  = diameter of structural cell

$d_a$  = diameter of mean area per stem

$s_e$  = mean obstacle spacing

Speed made good  
versus mean obstacle spacing

29. Tests in fine-grained soils and sands with fines, poorly drained.

Plots of speed made good versus mean obstacle spacing for tests conducted on nearly level surfaces of fine-grained soils and sands with fines, poorly drained, are shown in plate B1. The curves drawn through the data points represent lines of visual best fit. In fig. 1, plate B1, it can be seen that tests 242 and 243 had very nearly the same speed made good with a 2.5-ft difference in obstacle spacing. This was probably due to the selection of route by the driver. The actual speed for test 243 was 1.6 mph higher than that for test 242, but the path elongation ratio was 1.14 for test 243 and only 1.02 for test 242 and the speed made good reflected the longer route. The go or no go point on the ordinate in fig. 2, plate B1, is well established by tests 12 and 13B, which indicate spacings too small to permit passage of the M37, and test 13A, which represents a barely go condition. The data do not indicate why there was a 2.8-mph difference in speed made good for tests 263 and 264 in fig. 3 at approximately the same mean obstacle spacing. However, an average value for the two tests would be 14.4 mph and the deviation from this average is only  $\pm 10$  percent. The location of the intercept of the curve in fig. 3, plate B1, with the abscissa was admittedly influenced by the tests on coarse-grained soils (paragraph 31). A comparison of the performances of the three wheeled vehicles is shown in fig. 4, plate B1. The curves indicate that the M151 performed best under the conditions tested. This was to be expected because of the size and maneuverability of the vehicle. The increase in the performance of the M35A1 over that of the M37 at higher mean obstacle spacing was probably due to the better acceleration of the M35A1.\*

30. The intercept of the performance curve with the abscissa in fig. 5, plate B1, is defined by test 15A in which the vehicle was barely able to proceed. The slightly narrower spacing encountered during test 15B nearby was sufficient to prohibit passage of the vehicle. The curve shown

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\* R. F. Depkin, "Wheeled Vehicle Performance Data Consolidation," June 1967, Aberdeen Proving Ground, Md.

in fig. 6, plate B1, was drawn without reference to test 29, a notable outlier. A careful review of the data from this test reveals no reason for the vehicle's poor showing in the indicated spacing. Barring this test, however, the scatter of the data in this figure, while somewhat more than might be desirable, does not appear excessive. The comparison of the performances of the M29C and the M113 in fig. 7, plate B1, indicates that the smaller vehicle, the M29C, was able to maneuver through narrower spacings at a higher rate of speed made good than the M113 in the vegetation assemblages tested.

31. Tests in coarse-grained (SP) soils. Plots of speed made good versus mean obstacle spacing for tests conducted upslope and downslope in coarse-grained soils are shown in plate B2. A line that best separates upslope and downslope points is drawn on each plot. In figs. 1, 2, 5, and 6 of plate B2 the intercept of the line of separation with the abscissa was made to coincide with that shown in the corresponding figures in plate B1, while the intercept from the plot in fig. 3, plate B2 (the M35A1 tests), was transferred to the respective plot in plate B1. The line represents an approximation of the speed made good to be expected on level sandy soils.\* Where the location of the line was doubtful, judgment was aided by the examination of the location and curvature of lines on better defined plots. Examination of the plots in plate B2 shows that the downslope tests tend to fall above and to the left of the separation line. The total number of plotted points for each set of data, the number that do not fall on the correct side of the separation line, and the percent falling on the proper side are given below. The last column in the tabulation below shows the percent of the total number of points that are on the correct side or the safe side. (An upslope speed greater than the line of separation indicates is considered to be on the safe side.)

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\* It is theoretically possible that the values of speed made good could be corrected for the effect of slope, but such an attempt is beyond the scope of this investigation.

| <u>Vehicle</u> | <u>Total<br/>Number<br/>of Points</u> | <u>Number<br/>Not Con-<br/>forming</u> | <u>Percent<br/>Correct</u> | <u>Percent Cor-<br/>rect or on<br/>the Safe Side</u> |
|----------------|---------------------------------------|--|----------------------------|--|
| M151           | 12                                    | 1                                      | 92                         | 92   |
| M37            | 10                                    | 2                                      | 80                         | 90   |
| M35A1          | 9                                     | 1                                      | 89                         | 89   |
| M29C           | 17                                    | 2                                      | 88                         | 100  |
| M113           | 9                                     | 0                                      | 100                        | 100  |

32. Note that only three points do not fall on the correct or safe side (tests 295, 266, and 291). When all tests are considered together the percent accuracy is 94.7, well above the acceptable limit for experimental error.

33. The summary curves for the wheeled vehicle tests in coarse-grained soils, fig. 4, plate B2, follow the same trend as those for fine-grained soils shown in plate B1; however, the speed at which the M35A1 begins to excel the M37 is somewhat lower. Again this may be the result of greater acceleration of the M35A1, and may also suggest that the influence of soil strength on speed in lateral obstacles varies with soil type. The summary curves for tracked vehicles are quite similar to those in plate B1, as would be expected.

#### Minimum obstacle spacing required

34. The mean obstacle spacing corresponding to a vehicle speed of 2 mph as indicated in plates B1 and B2 was considered to be the minimum obstacle spacing ( $\min s_e$ ) required for each of the vehicles tested. Attempts to relate this value to various vehicle characteristics revealed that the vehicle width yielded the best correlation. A plot of vehicle width ( $w$ ) versus mean obstacle spacing is shown in plate B3. The line of best visual fit, extrapolated, passes through the origin. From this plot it can be seen that the minimum obstacle spacing required for the vehicles tested was 1.4 times the vehicle width.

35. It is obvious that the relation expressed in the paragraph above and in plate B3 will not hold true for all vehicles. Certainly vehicle length and turning radius can also affect the minimum obstacle spacing negotiable. Nor can it be assumed that this relation is valid for all

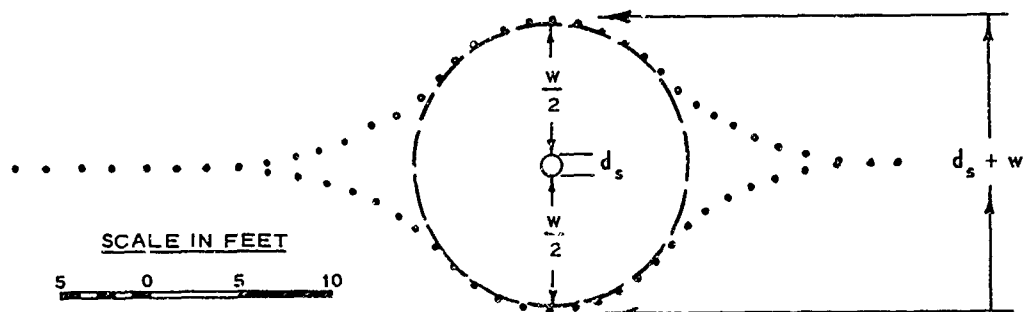
vegetation assemblages (since  $s_e$  ignores tree diameter, stilt or buttress roots, and branching habit). Nevertheless, for the range of vehicle tested and the conditions encountered, minimum obstacle spacing required can be determined from vehicle width ( $w$ ) by the equation

$$\min s_e = 1.4w$$

### Speed-Area Denied Relations

36. In an attempt to account for the effect of the diameters of the trees on speed made good (not considered in the mean obstacle spacing analysis) and to recognize the practical fact that a moving vehicle (especially a fast-moving one) cannot safely avail itself of every foot of space between two trees, the concept of "area denied" was evolved. Since it was clear from the analysis of the minimum mean spacing required by a vehicle (see plate B3) that the vehicle width was a significant parameter, it was felt that vehicle width should play a part in the concept.

37. Accordingly area denied ( $A_d$ ) by a single tree was defined as the area encompassed by a circle whose diameter was equal to the stem diameter ( $d_s$ ) plus the vehicle width ( $w$ ). An example of the computation is shown in fig. B11. Note that although the area of the dashed circle



$$A_d = \frac{\pi}{4} (d_s + w)^2$$

#### LEGEND

..... PATH OF POINT ON CENTER LINE OF VEHICLE

$d_s$  = STEM DIAMETER

$w$  = VEHICLE WIDTH

TEST 293

SITE E 1

Fig. B11. Example of area denied by a single tree



is called "area denied" only that portion of the circle represented by the tree itself is truly denied to a (slow-moving) vehicle.

Percent area denied

38. The percent area denied equals the total area denied divided by the area of the structural cell, multiplied by 100. The equation for computing percent area denied ( $\%A_d$ ) in a structural cell is

$$\%A_d = \frac{20(\bar{d}_s + w)^2}{D_c^2} \times 100$$

An example of the computation for test 293 is given below.

$$\bar{d}_s = 6.2 \text{ in.}; w = 8.0 \text{ ft}; D_c = 58 \text{ ft}$$

$$\%A_d = \frac{20\left(\frac{6.2}{12} + 8.0\right)^2}{(58)^2} \times 100$$

$$\%A_d = 0.429 \times 100$$

$$\%A_d = 43$$

Percent area denied  
versus speed made good

39. Tests in fine-grained soils and sands with fines, poorly drained. Plots of speed made good versus percent area denied for tests conducted on nearly level fine-grained soils and sands with fines, poorly drained, are shown in plate B4. The curves drawn through the plotted points represent the lines of best visual fit.

40. The comparison of the curves for the wheeled vehicles indicates the highest average speed made good for a given area denied was recorded for the M35A1, lowest for the M37, and the M151 in between. The relative positions of the curves thus differ somewhat from the speed-spacing relation as a result of the width of the vehicle affecting the area denied. The comparison of the curves for the tracked vehicles reflects the same result and for the same reason.

41. Tests in coarse-grained soils. Plots of speed made good versus percent area denied for upslope and downslope tests on coarse-grained soils are shown in plate B5. A line that best separates upslope and downslope test points is drawn on each plot. Examination of the plots shows that, in general, the downslope tests fall above and to the right of the separation line. The total number of plotted points for each set of data, the number that do not fall on the correct side of the separation line, and the percent falling on the proper side are given below. The last column in the tabulation below shows the percent of the total number of points that are on the correct side or safe side. (An upslope speed greater than the line of separation indicates is considered to be on the safe side.)

| <u>Vehicle</u> | <u>Total<br/>Number<br/>of Points</u> | <u>Number<br/>Not Con-<br/>forming</u> | <u>Percent<br/>Correct</u> | <u>Percent Cor-<br/>rect or on<br/>the Safe Side</u> |
|----------------|---------------------------------------|--|----------------------------|--|
| M151           | 12                                    | 1                                      | 92                         | 92   |
| M37            | 10                                    | 1                                      | 90                         | 100  |
| M35A1          | 9                                     | 2                                      | 78                         | 89   |
| M29C           | 17                                    | 2                                      | 88                         | 100  |
| M113           | 9                                     | 0                                      | 100                        | 100  |

From the tabulation above note that only two tests are not on the correct side, and that the overall accuracy is somewhat improved over the comparative mean obstacle spacing plots (paragraphs 31 and 32).

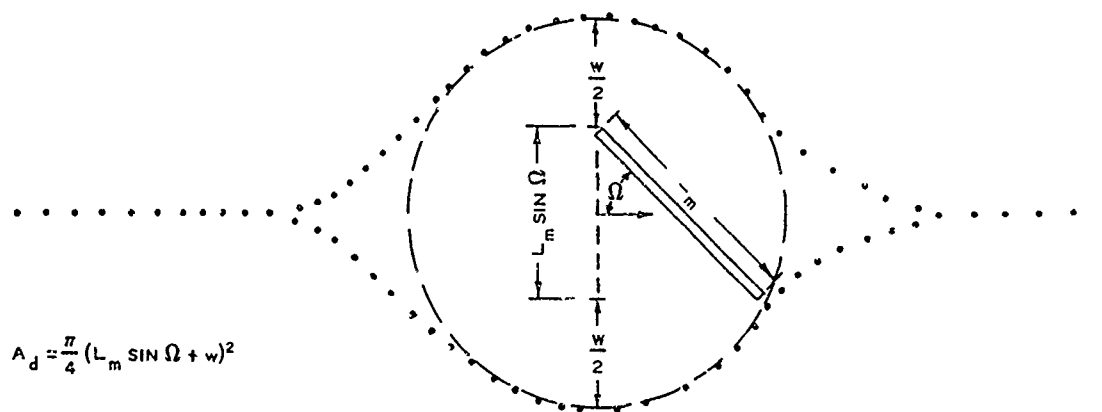
42. A comparison of the performances of the wheeled vehicles is shown in fig. 4, plate B5, and of the tracked vehicles in fig. 7, plate B5. The relative positions of the curves in both figures are the same as in fine-grained soils, plate B4; however, the separation between the curves is distinctly greater. Again this suggests that factors other than those being considered may have significant effect on the speed made good in lateral obstacles.

Other possibilities for  
use of percent area denied

43. In the tests described herein, all obstacles were tree stems. For other obstacles such as boulders, termite mounds, logs, etc., it is considered possible to apply the area denied principle for all such types

of obstacles by using the following procedures: (a) determine a structural cell diameter  $D_c$  for each type of lateral obstacle, e.g. trees, stumps, mounds; (b) convert the area occupied by each lateral obstacle to an equivalent circular area and determine the average diameter  $\bar{d}_o$ ; (c) substitute  $D_c$ ,  $\bar{d}_o$  ( $\bar{d}_o$  is equivalent to  $\bar{d}_s$ ), and vehicle width  $w$  into the equation given in paragraph 38 and compute the percent area denied; and (d) sum the values of percent area denied computed for each obstacle type to determine the total percent area denied. Trees or boulders occurring within an area denied by logs or termite mounds are excluded from the computation of area denied.

44. The area denied by a log is dependent upon the orientation of the log with respect to the direction of vehicle travel. Fig. B12 illustrates the computation for area denied by a log when the vehicle approaches at an angle  $\Omega$ . Since the angle  $\Omega$  is not known,  $\sin \Omega$  is arbitrarily selected as 0.635 which is the average sine of all angles between 0 and 90 deg.



#### LEGEND

- ..... PATH OF POINT ON CENTER LINE OF VEHICLE
- $L_m$  = LENGTH OF LOG
- $\Omega$  = ANGLE FORMED BY LOG AND DIRECTION OF VEHICLE TRAVEL
- $w$  = VEHICLE WIDTH

Fig. B12. Example of area denied by log

#### Notes, Observations, and Other Data Considered

45. Many factors, measurable or unmeasurable, highly significant or

very subtle, can influence the speed made good of a vehicle traversing an area containing lateral obstacles. The following list shows those that are presumed to have some effect. Among those measurable are some for which data can be found in table B2. That these data are not used in the analysis is no reflection on their validity or quality. The effect of the parameters they represent may have been obscured by less subtle influences; current research may bring to light a better understanding of their specific influence.

a. Vehicle factors.

- (1) Overall width
- (2) Overall length
- (3) Wheelbase
- (4) Turning radius
- (5) Power
- (6) Weight
- (7) Steering response rate
- (8) Mechanical condition

b. Terrain factors.

- (1) Size of obstacles
- (2) Shape of obstacles
- (3) Density of obstacles
- (4) Soil strength
- (5) Soil surface condition
- (6) Slope
- (7) Visibility

c. Driver factors.

- (1) Recognition distance
- (2) Reaction time
- (3) Clearance tolerance
- (4) Ride dynamics tolerance

46. Equations and empirical relations employing many of the vehicle and terrain factors listed above for use in a first-generation analytical model for predicting speed performance in lateral obstacles have been developed. Vehicle testing programs are being continued to verify the

various relations in the analytical model.

47. The problem of interrelating the factors influencing vehicle performance in lateral obstacles is not lessened when it is realized that the degree of influence of some of the factors varies inversely with the influence of others. For instance, in the tests resulting in low speeds, such vehicle factors as width, length, wheelbase, and turning radius, and such terrain factors as size and spacing of obstacles appeared most significant. In the tests resulting in higher speeds, vehicle and driver factors such as power, weight, steering response rate, and reaction time, and terrain factors such as soil strength, surface condition, slope, and visibility seemed to be of prime importance. From observation only, it was noted that driver influence was most significant when speeds exceeded 8 to

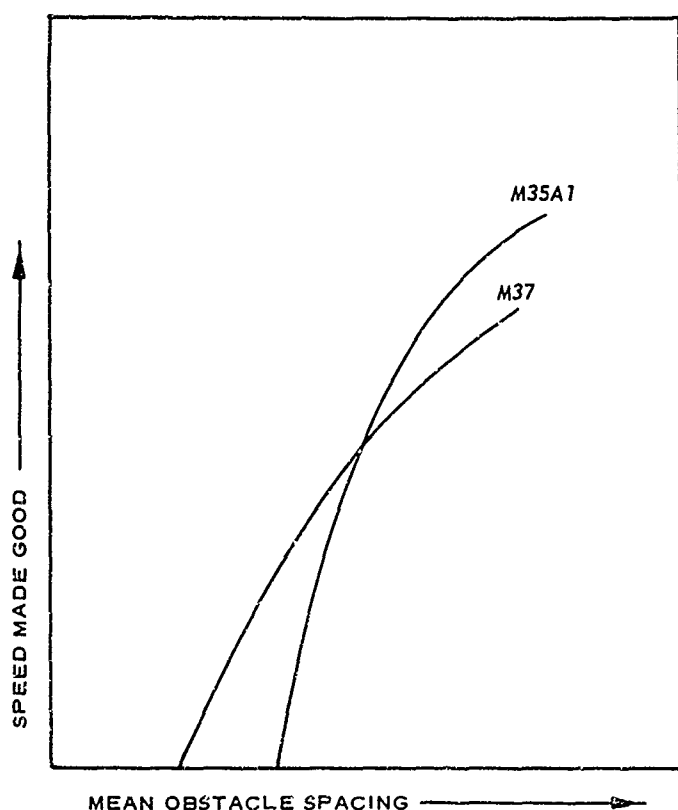


Fig. B13. Comparison of the speed made good-mean obstacle spacing curves for the M37 and M35A1

10 mph. Differences in vehicle performances can be demonstrated by comparing the shape of the speed made good versus obstacle spacing curves for the M37 and M35A1 (fig. B13). Below the point of intersection of the two curves speed made good is controlled mainly by vehicle geometry and spacing. Above this point other vehicle and terrain factors begin to assume significance as do the driver factors. Yet the steepness of the M35A1 curve suggests that the vehicle's capability for acceleration exerts influence even at small obstacle spacings.

## PART IV: CONCLUSIONS AND RECOMMENDATIONS

### Conclusions

48. Based on the analysis of the data herein and subject to the limits imposed by these data, the following conclusions are offered:

- a. Performance of wheeled and tracked vehicles in terms of speed made good in a structurally simple vegetation assemblage can be correlated empirically with the density of the vegetation assemblage expressed as mean obstacle spacing (paragraphs 29-33).
- b. The minimum obstacle spacing required to permit movement of standard vehicles is a function of the width of the vehicles (plate B3).
- c. Vehicle performance in terms of speed made good in lateral obstacles can be empirically correlated with area denied (paragraphs 39-42).
- d. The speed made good that a vehicle can achieve when maneuvering in lateral obstacles is significantly affected by the slope of the terrain (plates B2 and B4).

### Recommendations

49. It is recommended that:

- a. Tests be conducted in a range of artificial lateral obstacle spacings on a surface sufficiently strong to eliminate the effect of soil strength in order to establish empirical relations between:
  - (1) Average turning radius and obstacle spacing.
  - (2) Minimum acceleration required and obstacle spacing.
  - (3) Average speed and obstacle clearance.
- b. Inasmuch as there is some indication that soil strength has a significant effect on vehicle performance in lateral obstacles, additional tests be made to establish speed-spacing relations for a wide range of soil strengths.
- c. The relations of a and b above be integrated into the model for predicting vehicle speed in lateral obstacles.
- d. Tests be conducted in selected naturally occurring combinations of lateral obstacles and soil strengths to validate the prediction model.

Table B1  
Pertinent Vehicle Characteristics

| Vehicle | Test Weight<br>lb | Track                 |              |             | Contact Pressure<br>psi | Pogies in Contact<br>w/Each Side | Ground Clearance<br>in. | Engine     |                  | Transmission                        | Width<br>ft | Length<br>ft | Turning Radius<br>ft | Tires    |            |
|---------|-------------------|-----------------------|--------------|-------------|-------------------------|----------------------------------|-------------------------|------------|------------------|-------------------------------------|-------------|--------------|----------------------|----------|------------|
|         |                   | Contact Length<br>in. | Width<br>in. | Shoe<br>in. |                         |                                  |                         | Type       | Brake Horsepower |                                     |             |              |                      | Size     | Ply Rating |
| M29C    | 5,600             | 78                    | 20           | 6           | --                      | 8                                | 11                      | Gasoline   | 65               | Manual, synchromesh                 | 5.6         | 16.0         | 12.0                 | --       | --         |
| M113    | 19,151-23,896     | 105                   | 15           | 6           | 7.5                     | 5                                | 16.1                    | Gasoline   | 215              | Hydraulic, single stage, multiphase | 8.8         | 16.0         | 12.6                 | --       | --         |
| M151    | 3,000             | --                    | --           | --          | --                      | --                               | 9.3                     | Gasoline   | 71               | Manual, synchromesh                 | 5.2         | 11.5         | 17.9                 | 7.00-16  | 6          |
| M37     | 7,350-7,645       | --                    | --           | --          | --                      | --                               | 10.75                   | Gasoline   | 78               | Manual, synchromesh                 | 6.1         | 15.8         | 26.0                 | 9.00-20  | 8          |
| M35A1   | 19,360            | --                    | --           | --          | --                      | --                               | 12.7                    | Multifired | 146              | Manual, synchromesh                 | 8.0         | 22.8         | 36.0                 | 11.00-20 | 9          |

Table B2  
Summary of Data and Test Results

| No                                | Test Site* | Date    | Straight-Line Distance (D <sub>s</sub> ) | Actual Path Length (D <sub>p</sub> ) | Path Elongation Ratio (D <sub>p</sub> /D <sub>s</sub> ) | Total Time (t) | Mean Vegetation Structural Cell Diam (D <sub>c</sub> ) | Mean Costacle Spacing (s <sub>c</sub> ) | Percent Area Denied (A <sub>d</sub> ) | Slope % | Actual Speed | Speed Made Good | Wheel Slip % | Unified Soil Classification |                    |                     |
|-----------------------------------|------------|---------|--|--------------------------------------|---|----------------|--|---|---------------------------------------|---------|--------------|-----------------|--------------|-----------------------------|--------------------|---------------------|
|                                   |            |         | ft                                       | ft                                   |   | sec            | ft   | ft                                      |                                       |         |              | mph             | mph          |                             | 0- to 6- in. Layer | 6- to 12- in. Layer |
|                                   |            |         | M51, 1/2-ton, 4x4 Utility Truck          |                                      |   |                |  |   |                                       |         |              |                 |              |                             |                    |                     |
| 240                               | NASA1      | 3/29/65 | 428                                      | 434                                  | 1.01  | 16.0           | 117  | 26.2                                    | 5                                     | 0       | 18.5         | 19.2            | †            | ML                          | CL-ML              |                     |
| 241                               | NASA1      | 3/29/65 | 570                                      | 580                                  | 1.02  | 24.0           | 109  | 24.4                                    | 6                                     | 0       | 16.5         | 16.2            | †            | ML                          | CL-ML              |                     |
| 242                               | NASA2      | 3/30/65 | 241                                      | 245                                  | 1.02  | 15.0           | 54   | 12.1                                    | 24                                    | 0       | 11.2         | 11.0            | †            | ML                          | CL-ML              |                     |
| 243                               | NASA2      | 3/30/65 | 191                                      | 218                                  | 1.14  | 11.6           | 65   | 14.6                                    | 16                                    | 0       | 12.8         | 11.2            | †            | ML                          | CL-ML              |                     |
| 251                               | NASA3      | 3/31/65 | 132                                      | 143                                  | 1.08  | 42.0           | 34   | 7.6                                     | 54                                    | 0       | 2.3          | 2.1             | †            | ML                          | CL-ML              |                     |
| 269                               | F4         | 4/9/65  | 262                                      | 262                                  | 1.00  | 11.5           | 51   | 13.7                                    | 17                                    | -12.6   | 15.5         | 15.5            | †            | SP                          | SP                 |                     |
| 270                               | E4         | 4/9/65  | 237                                      | 248                                  | 1.05  | 20.0           | 68   | 15.2                                    | 13                                    | -11.4   | 8.4          | 8.1             | †            | SP                          | SP                 |                     |
| 271                               | E4         | 4/9/65  | 197                                      | 197                                  | 1.00  | 9.6            | 70   | 15.7                                    | 13                                    | +2.0    | 14.0         | 14.0            | †            | SP                          | SP                 |                     |
| 278                               | F3         | 4/10/65 | 307                                      | 313                                  | 1.02  | 20.5           | 60   | 13.4                                    | 18                                    | +9.8    | 10.4         | 10.2            | †            | SP                          | SP                 |                     |
| 279                               | E3         | 4/10/65 | 296                                      | 307                                  | 1.04  | 20.4           | 58   | 13.0                                    | 19                                    | +9.8    | 10.3         | 9.9             | †            | SP                          | SP                 |                     |
| 280                               | E3         | 4/10/65 | 192                                      | 198                                  | 1.03  | 12.9           | 51   | 11.4                                    | 24                                    | -0.5    | 10.5         | 10.1            | †            | SP                          | SP                 |                     |
| 283A                              | E2         | 4/13/65 | 400                                      | 450                                  | 1.12  | 45.0           | 52   | 11.6                                    | 26                                    | +7.5    | 6.8          | 6.1             | †            | SP                          | SP                 |                     |
| 284                               | E2         | 4/13/65 | 412                                      | 421                                  | 1.02  | 30.5           | 45   | 10.8                                    | 30                                    | -6.6    | 9.4          | 9.2             | †            | SP                          | SP                 |                     |
| 294                               | E1         | 4/14/65 | 186                                      | 194                                  | 1.04  | 13.4           | 48   | 16.8                                    | 28                                    | -8.1    | 9.9          | 9.5             | †            | SP                          | SP                 |                     |
| 295                               | E1         | 4/14/65 | 310                                      | 317                                  | 1.02  | 17.0           | 69   | 15.5                                    | 14                                    | -2.6    | 12.7         | 12.4            | †            | SP                          | SP                 |                     |
| 296                               | E1         | 4/14/65 | 167                                      | 172                                  | 1.03  | 10.5           | 86   | 19.3                                    | 9                                     | +11.4   | 11.2         | 10.8            | †            | GP                          | SP                 |                     |
| 297                               | E1         | 4/14/65 | 320                                      | 331                                  | 1.03  | 19.0           | 61   | 13.7                                    | 17                                    | +1.6    | 11.9         | 11.5            | †            | SP                          | SP                 |                     |
| M37, 3/4-ton, 4x4 Cargo Truck     |            |         |  |                                      |   |                |  |   |                                       |         |              |                 |              |                             |                    |                     |
| 1                                 | NASA1      | 7/29/64 | 442                                      | 446                                  | 1.01  | 22.2           | 118  | 26.4                                    | 6                                     | 0       | 13.7         | 13.6            | 0            | ML                          | CL-ML              |                     |
| 2                                 | NASA1      | 7/29/64 | 782                                      | 789                                  | 1.01  | 39.7           | 106  | 23.7                                    | 8                                     | 0       | 13.6         | 13.4            | 0            | ML                          | CL-ML              |                     |
| 9                                 | NASA2      | 8/5/64  | 520                                      | 531                                  | 1.02  | 47.3           | 62   | 13.9                                    | 24                                    | 0       | 7.6          | 7.5             | 0            | ML                          | CL-ML              |                     |
| 10                                | NASA2      | 8/5/64  | 471                                      | 479                                  | 1.02  | 50.0           | 61   | 13.7                                    | 25                                    | 0       | 6.5          | 6.4             | 0            | ML                          | CL-ML              |                     |
| 12                                | NASA3      | 3/5/64  | 290                                      | †                                    | †   | †              | 34   | 6.7                                     | 93                                    | 0       | 0            | 0               | †            | ML                          | CL-ML              |                     |
| 13A                               | NASA3      | 8/5/64  | 294                                      | †                                    | †   | †              | 38   | 8.5                                     | 58                                    | 0       | 0.2          | 0.2             | †            | ML                          | CL-ML              |                     |
| 13B                               | NASA3      | 8/5/64  | 294                                      | †                                    | †   | †              | 36   | 8.1                                     | 64                                    | 0       | 0            | 0               | †            | ML                          | CL-ML              |                     |
| 22                                | NASA4      | 8/18/64 | 587                                      | 597                                  | 1.02  | 35.0           | 80   | 17.9                                    | 15                                    | 0       | 11.6         | 11.4            | †            | SM                          | SM                 |                     |
| 23                                | NASA4      | 8/18/64 | 552                                      | 570                                  | 1.03  | 35.0           | 77   | 17.2                                    | 16                                    | 0       | 11.1         | 10.8            | †            | SM                          | SM                 |                     |
| 265                               | E1         | 4/8/65  | 281                                      | 294                                  | 1.05  | 23.4           | 73   | 16.4                                    | 16                                    | +6.8    | 8.5          | 8.2             | ††           | SP                          | SP                 |                     |
| 266                               | E1         | 4/8/65  | 289                                      | 297                                  | 1.03  | 18.9           | 73   | 16.4                                    | 16                                    | -2.2    | 10.7         | 10.4            | ††           | SP                          | SP                 |                     |
| 267                               | E1         | 4/8/65  | 240                                      | 257                                  | 1.07  | 18.8           | 71   | 15.0                                    | 17                                    | +1.9    | 9.3          | 8.7             | ††           | SP                          | SP                 |                     |
| 277                               | E4         | 4/9/65  | 216                                      | 229                                  | 1.06  | 14.0           | 68   | 15.1                                    | 18                                    | -11.9   | 11.2         | 10.5            | 4            | SP                          | SP                 |                     |
| 273                               | E4         | 4/9/65  | 197                                      | 200                                  | 1.02  | 14.0           | 64   | 14.3                                    | 20                                    | +10.2   | 9.8          | 9.6             | ††           | SP                          | SP                 |                     |
| 274                               | E4         | 4/9/65  | 156                                      | 170                                  | 1.09  | 13.9           | 65   | 14.6                                    | 20                                    | +5.6    | 8.3          | 7.7             | 5            | SP                          | SP                 |                     |
| 275                               | E3         | 4/9/65  | 232                                      | 242                                  | 1.04  | 27.6           | 52   | 11.6                                    | 34                                    | +9.5    | 6.0          | 5.7             | 5            | SP                          | SP                 |                     |
| 276                               | E3         | 4/9/65  | 287                                      | 294                                  | 1.02  | 23.8           | 54   | 12.1                                    | 29                                    | -8.3    | 8.4          | 8.2             | 4            | SP                          | SP                 |                     |
| 277                               | E3         | 4/9/65  | 146                                      | 162                                  | 1.11  | 18.9           | 63   | 14.1                                    | 21                                    | +3.2    | 5.8          | 5.3             | 4            | SP                          | SP                 |                     |
| 281                               | E2         | 4/12/65 | 386                                      | 410                                  | 1.06  | 61.3           | 55   | 12.3                                    | 30                                    | +5.9    | 4.6          | 4.3             | 3            | SP                          | SP                 |                     |
| 282                               | E2         | 4/12/65 | 408                                      | 496                                  | 1.22  | ††             | †  | †                                       | †                                     | -5.6    | †            | †               | ††           | SP                          | SP                 |                     |
| M35A1, 2-1/2-ton, 6x6 Cargo Truck |            |         |  |                                      |   |                |  |   |                                       |         |              |                 |              |                             |                    |                     |
| 252                               | NASA2      | 3/31/65 | 254                                      | 259                                  | 1.02  | 28.0           | 64   | 14.3                                    | 37                                    | 0       | 6.3          | 6.2             | 7            | ML                          | CL-ML              |                     |
| 253                               | NASA2      | 4/1/65  | 445                                      | 472                                  | 1.06  | 39.0           | 66   | 14.8                                    | 35                                    | 0       | 8.3          | 7.8             | 0            | ML                          | CL-ML              |                     |
| 263                               | NASA1      | 4/5/65  | 649                                      | 653                                  | 1.01  | 28.0           | 105  | 23.5                                    | 13                                    | 0       | 15.9         | 15.8            | 0            | ML                          | CL-ML              |                     |
| 264                               | NASA1      | 4/5/65  | 707                                      | 735                                  | 1.04  | 37.0           | 106  | 23.7                                    | 13                                    | 0       | 13.5         | 13.0            | 0            | ML                          | CL-ML              |                     |
| 285                               | E3         | 4/13/65 | 114                                      | 150                                  | 1.04  | 23.7           | 55   | 12.3                                    | 47                                    | +9.6    | 4.3          | 4.1             | 1            | SP                          | SP                 |                     |
| 286                               | E3         | 4/13/65 | 124                                      | 128                                  | 1.03  | 37.9           | 52   | 11.6                                    | 53                                    | -8.5    | 2.3          | 2.2             | 0            | SP                          | SP                 |                     |
| 287                               | E4         | 4/13/65 | 184                                      | 187                                  | 1.02  | 9.7            | 68   | 15.2                                    | 30                                    | -10.3   | 13.2         | 12.9            | 0            | SP                          | SP                 |                     |
| 288                               | E4         | 4/13/65 | 185                                      | 189                                  | 1.02  | 28.3           | 62   | 13.9                                    | 36                                    | +9.3    | 4.6          | 4.5             | 6            | SP                          | SP                 |                     |
| 289                               | E4         | 4/13/65 | 148                                      | 154                                  | 1.04  | 14.3           | 70   | 15.7                                    | 28                                    | +2.8    | 7.4          | 7.1             | 2            | SP                          | SP                 |                     |
| 290                               | E1         | 4/14/65 | 173                                      | 175                                  | 1.01  | 9.5            | 73   | 16.4                                    | 27                                    | +2.2    | 12.5         | 12.4            | 5            | SP                          | SP                 |                     |
| 291                               | E1         | 4/14/65 | 347                                      | 366                                  | 1.05  | 30.0           | 73   | 16.4                                    | 27                                    | +4.9    | 8.3          | 7.9             | 0            | SP                          | SP                 |                     |
| 292                               | E1         | 4/14/65 | 168                                      | 169                                  | 1.01  | 14.3           | 72   | 16.1                                    | 28                                    | +7.4    | 6.1          | 8.0             | 4            | SP                          | SP                 |                     |
| 293                               | †          | 4/14/65 | 142                                      | 146                                  | 1.03  | 14.3           | 58   | 13.0                                    | 43                                    | +0.6    | 6.9          | 6.8             | 4            | SP                          | SP                 |                     |

\* See description in text of test areas and test sites.

\*\* C<sub>pl</sub> = cohesion (psi), rubber to litter, β<sub>pl</sub> = friction angle (degrees), rubber to litter, C<sub>rs</sub> = cohesion (psi), rubber to soil, β<sub>rs</sub> = friction angle (degrees), n

† No measurement made.

†† Instrumentation failure.

A



Table B2  
Summary of Data and Test Results

| Slope<br>#                                    |      | Actual<br>Speed<br>mph | Speed<br>Made<br>Good<br>mph | Wheel<br>Slip<br>% | Soils Data                     |                        |                                   |                        |                       |                        |                       |                        |                       |                        |                       |                        |                       |                        |                       |                        |                       |                        |                            |                        |       |             |  |
|---|------|------------------------|------------------------------|--------------------|--------------------------------|------------------------|-----------------------------------|------------------------|-----------------------|------------------------|-----------------------|------------------------|-----------------------|------------------------|-----------------------|------------------------|-----------------------|------------------------|-----------------------|------------------------|-----------------------|------------------------|----------------------------|------------------------|-------|-------------|--|
|   |      |                        |                              |                    | Unified Soil<br>Classification |                        | Average Cone Index at Depths, in. |                        |                       |                        |                       |                        |                       |                        | Rating Cone Index     |                        | Shearograph Data**    |                        |                       |                        |                       |                        | Moisture Content           |                        |       | Dry Density |  |
|   |      |                        |                              |                    |                                |                        |                                   |                        |                       |                        |                       |                        |                       |                        |                       |                        |                       |                        |                       |                        |                       |                        | Percent of Dry Soil Weight |                        |       | pcf         |  |
|   |      |                        |                              |                    | 0- to 6-<br>in. Layer          | 6- to 12-<br>in. Layer | 0- to 6-<br>in. Layer             | 6- to 12-<br>in. Layer | 0- to 6-<br>in. Layer | 6- to 12-<br>in. Layer | 0- to 6-<br>in. Layer | 6- to 12-<br>in. Layer | 0- to 6-<br>in. Layer | 6- to 12-<br>in. Layer | 0- to 6-<br>in. Layer | 6- to 12-<br>in. Layer | 0- to 6-<br>in. Layer | 6- to 12-<br>in. Layer | 0- to 6-<br>in. Layer | 6- to 12-<br>in. Layer | 0- to 6-<br>in. Layer | 6- to 12-<br>in. Layer | 0- to 6-<br>in. Layer      | 6- to 12-<br>in. Layer |       |             |  |
| <u>M51, 1/4-ton, 4x4 Utility Truck (Jeep)</u> |      |                        |                              |                    |                                |                        |                                   |                        |                       |                        |                       |                        |                       |                        |                       |                        |                       |                        |                       |                        |                       |                        |                            |                        |       |             |  |
| 0   | 18.5 | 18.2                   | †                            | ML                 | CL-ML                          | 40                     | 69                                | 73                     | 89                    | 87                     | 84                    | 103                    | 23                    | 34                     | 2.0                   | 33.0                   | 0                     | 20                     | †                     | †                      | 58.1                  | 34.6                   | 30.5                       | 81.8                   | 87.6  |             |  |
| 0   | 16.5 | 16.2                   | †                            | ML                 | CL-ML                          | 28                     | 70                                | 67                     | 66                    | 68                     | 73                    | 83                     | 19                    | 26                     | 0.7                   | 38.0                   | 0.3                   | 21                     | 1.1                   | 16                     | 59.4                  | 36.3                   | 25.7                       | 80.9                   | 93.7  |             |  |
| 0   | 11.2 | 11.0                   | †                            | ML                 | CL-ML                          | 61                     | 107                               | 94                     | 84                    | 94                     | 110                   | 109                    | 29                    | 32                     | 1.6                   | 28.0                   | 0.9                   | 20                     | 0.9                   | 29                     | 63.5                  | 32.2                   | 25.5                       | 78.2                   | 91.2  |             |  |
| 0   | 12.8 | 11.2                   | †                            | ML                 | CL-ML                          | 59                     | 99                                | 88                     | 78                    | 72                     | 85                    | 98                     | 27                    | 33                     | 1.6                   | 28.0                   | 0.9                   | 20                     | 0.9                   | 29                     | 50.2                  | 27.6                   | 24.5                       | 83.8                   | 92.8  |             |  |
| 0   | 2.3  | 2.1                    | †                            | ML                 | CL-ML                          | 13                     | 191                               | 219                    | 195                   | 197                    | 210                   | 210                    | 47                    | 59                     | 0                     | 34.0                   | 0                     | 28                     | 0                     | 20                     | 44.2                  | 26.7                   | 20.5                       | 83.8                   | 97.4  |             |  |
| -12.6   | 15.5 | 15.5                   | †                            | SP                 | SP                             | 34                     | 78                                | 78                     | 73                    | 65                     | 70                    | 75                     | †                     | †                      | 0                     | 27.0                   | 0                     | 27                     | 0                     | 28                     | 14.2                  | 5.7                    | 5.9                        | 91.2                   | 94.8  |             |  |
| +11.4   | 8.4  | 8.1                    | †                            | SP                 | SP                             | 32                     | 64                                | 75                     | 67                    | 73                     | 77                    | 81                     | †                     | †                      | 0                     | 30.0                   | 0                     | 23                     | 0                     | 25                     | 3.9                   | 3.7                    | 4.8                        | 91.2                   | 92.8  |             |  |
| +2.0  | 14.0 | 14.0                   | †                            | SP                 | SP                             | 33                     | 71                                | 76                     | 70                    | 69                     | 73                    | 78                     | †                     | †                      | 0                     | 28.0                   | 0                     | 25                     | 0                     | 25                     | 9.0                   | 4.7                    | 5.3                        | 91.2                   | 93.8  |             |  |
| +9.8  | 10.4 | 10.2                   | †                            | SP                 | SP                             | 30                     | 78                                | 68                     | 70                    | 78                     | 77                    | 90                     | †                     | †                      | 0                     | 32.0                   | 0                     | 28                     | 0                     | 28                     | 4.4                   | 5.9                    | 5.2                        | 86.2                   | 93.7  |             |  |
| +9.8  | 10.3 | 9.9                    | †                            | SP                 | SP                             | 27                     | 86                                | 87                     | 72                    | 66                     | 74                    | 84                     | †                     | †                      | 0                     | 27.0                   | 0                     | 24                     | 0                     | 25                     | 4.5                   | 4.1                    | 4.3                        | 89.1                   | 90.1  |             |  |
| -0.5  | 10.5 | 10.1                   | †                            | SP                 | SP                             | 29                     | 82                                | 78                     | 71                    | 72                     | 75                    | 87                     | †                     | †                      | 0                     | 27.0                   | 0                     | 24                     | 0                     | 25                     | 4.5                   | 5.0                    | 4.7                        | 87.5                   | 91.5  |             |  |
| +7.5  | 6.8  | 6.1                    | †                            | SP                 | SP                             | 53                     | 146                               | 146                    | 136                   | 146                    | 198                   | 263                    | †                     | †                      | 0                     | 30.0                   | 0                     | 25                     | 0                     | 30                     | 5.5                   | 6.2                    | 5.8                        | 89.6                   | 98.3  |             |  |
| -6.6  | 9.4  | 9.2                    | †                            | SP                 | SP                             | 53                     | 146                               | 146                    | 136                   | 146                    | 198                   | 263                    | †                     | †                      | 0                     | 30.0                   | 0                     | 25                     | 0                     | 30                     | 5.5                   | 6.2                    | 5.8                        | 89.6                   | 98.3  |             |  |
| -8.1  | 5.9  | 5.5                    | †                            | SP                 | SP                             | 32                     | 99                                | 128                    | 116                   | 109                    | 115                   | 125                    | †                     | †                      | 1.7                   | 23.0                   | 0                     | 25                     | 0                     | 24                     | 1.7                   | 3.7                    | 4.8                        | 88.7                   | 92.9  |             |  |
| -2.6  | 12.7 | 12.4                   | †                            | SP                 | SP                             | 32                     | 92                                | 87                     | 108                   | 115                    | 114                   | 123                    | †                     | †                      | 0.3                   | 25.0                   | 0                     | 22                     | 0                     | 28                     | 2.8                   | 7.3                    | 5.3                        | 87.0                   | 97.0  |             |  |
| +11.4   | 11.2 | 10.8                   | †                            | SP                 | SP                             | 32                     | 92                                | 87                     | 108                   | 115                    | 114                   | 123                    | †                     | †                      | 0.3                   | 25.0                   | 0                     | 22                     | 0                     | 28                     | 2.8                   | 7.3                    | 5.3                        | 87.0                   | 97.0  |             |  |
| +1.6  | 11.9 | 11.5                   | †                            | SP                 | SP                             | 32                     | 99                                | 128                    | 116                   | 109                    | 115                   | 125                    | †                     | †                      | 1.7                   | 23.0                   | 0                     | 25                     | 0                     | 24                     | 1.7                   | 3.7                    | 4.8                        | 88.7                   | 92.9  |             |  |
| <u>M37, 3/4-ton, 4x4 Cargo Truck</u>          |      |                        |                              |                    |                                |                        |                                   |                        |                       |                        |                       |                        |                       |                        |                       |                        |                       |                        |                       |                        |                       |                        |                            |                        |       |             |  |
| 0   | 13.7 | 13.6                   | 0                            | ML                 | CL-ML                          | †                      | †                                 | †                      | †                     | †                      | †                     | †                      | †                     | †                      | †                     | †                      | †                     | †                      | †                     | †                      | †                     | †                      | †                          | †                      | †     |             |  |
| 0   | 13.6 | 13.4                   | 0                            | ML                 | CL-ML                          | 48                     | 112                               | 108                    | 103                   | 115                    | 132                   | 146                    | 22                    | 26                     | 0                     | 45.0                   | 1.7                   | 24                     | 1.7                   | 30                     | †                     | 37.5                   | 24.5                       | 82.0                   | 87.0  |             |  |
| 0   | 7.6  | 7.5                    | 0                            | ML                 | CL-ML                          | 118                    | 241                               | 192                    | 180                   | 196                    | 243                   | 250                    | †                     | †                      | †                     | †                      | 0                     | 34                     | 0                     | 43                     | †                     | †                      | †                          | †                      | †     |             |  |
| 0   | 6.5  | 6.4                    | 0                            | ML                 | CL-ML                          | 82                     | 176                               | 170                    | 172                   | 188                    | 218                   | 194                    | 26                    | 26                     | †                     | †                      | 0                     | 37                     | 0                     | 40                     | †                     | 34.4                   | 28.9                       | 84.4                   | 90.2  |             |  |
| 0   | 0    | 0                      | †                            | ML                 | CL-ML                          | 125                    | 209                               | 219                    | 250                   | 264                    | †                     | †                      | †                     | †                      | 0.2                   | 36.0                   | 0                     | 37                     | 0.3                   | 44                     | †                     | 21.0                   | 19.1                       | 88.7                   | 100.4 |             |  |
| 0   | 0.2  | 0.2                    | †                            | ML                 | CL-ML                          | 187                    | 342                               | 418                    | 379                   | 327                    | †                     | †                      | †                     | †                      | 0.2                   | 36.0                   | 0                     | 37                     | 0.3                   | 44                     | †                     | 22.9                   | 18.5                       | 81.8                   | 104.3 |             |  |
| 0   | 0    | 0                      | †                            | ML                 | CL-ML                          | †                      | †                                 | †                      | †                     | †                      | †                     | †                      | †                     | †                      | †                     | †                      | †                     | †                      | †                     | †                      | †                     | †                      | †                          | †                      | †     |             |  |
| 0   | 11.6 | 11.4                   | †                            | SM                 | SM                             | 41                     | 132                               | 250                    | 340                   | 362                    | 360                   | 381                    | †                     | †                      | 0                     | 38.0                   | 0                     | 33                     | 0                     | 42                     | †                     | 17.6                   | 13.2                       | 90.7                   | 108.3 |             |  |
| 0   | 11.1 | 10.8                   | †                            | SM                 | SM                             | 62                     | 222                               | 315                    | 354                   | 384                    | 355                   | 410                    | †                     | †                      | 0                     | 37.0                   | 0                     | 34                     | 0                     | 42                     | †                     | 23.6                   | 12.4                       | 84.6                   | 102.3 |             |  |
| +6.8  | 8.5  | 8.2                    | ††                           | SP                 | SP                             | 26                     | 82                                | 93                     | 93                    | 105                    | 114                   | 125                    | †                     | †                      | 0                     | 32.0                   | 0                     | 30                     | 0                     | 36                     | 4.0                   | 5.9                    | 6.2                        | 89.4                   | 94.1  |             |  |
| -2.2  | 10.7 | 10.4                   | ††                           | SP                 | SP                             | 27                     | 84                                | 103                    | 110                   | 120                    | 145                   | 174                    | †                     | †                      | 0                     | 35.0                   | 0                     | 25                     | 0                     | 30                     | 28.4                  | 16.9                   | 13.1                       | 84.6                   | 97.1  |             |  |
| +1.9  | 9.3  | 8.7                    | ††                           | SP                 | SP                             | 27                     | 84                                | 103                    | 110                   | 120                    | 145                   | 174                    | †                     | †                      | 0                     | 31.0                   | 0                     | 25                     | 0                     | 31                     | 28.4                  | 16.9                   | 13.1                       | 84.6                   | 97.1  |             |  |
| -11.9   | 11.2 | 10.5                   | †                            | SP                 | SP                             | 34                     | 78                                | 78                     | 73                    | 65                     | 70                    | 75                     | †                     | †                      | 0                     | 27.0                   | 0                     | 27                     | 0                     | 28                     | 14.2                  | 5.7                    | 5.9                        | 91.2                   | 94.8  |             |  |
| +10.2   | 9.8  | 9.6                    | ††                           | SP                 | SP                             | 32                     | 64                                | 75                     | 67                    | 73                     | 77                    | 81                     | †                     | †                      | 0                     | 30.0                   | 0                     | 23                     | 0                     | 25                     | 3.9                   | 3.7                    | 4.8                        | 91.2                   | 92.8  |             |  |
| +5.6  | 8.3  | 7.7                    | 5                            | SP                 | SP                             | 33                     | 71                                | 76                     | 70                    | 69                     | 73                    | 78                     | †                     | †                      | 0                     | 28.0                   | 0                     | 25                     | 0                     | 26                     | 9.0                   | 4.7                    | 5.3                        | 91.2                   | 93.8  |             |  |
| +9.5  | 6.0  | 5.7                    | 5                            | SP                 | SP                             | 30                     | 83                                | 81                     | 69                    | 73                     | 74                    | 80                     | †                     | †                      | 0                     | 29.0                   | 0                     | 25                     | 0                     | 32                     | 5.7                   | 6.9                    | 5.8                        | 93.9                   | 95.3  |             |  |
| -8.3  | 8.4  | 8.2                    | 0                            | SP                 | SP                             | 26                     | 88                                | 84                     | 75                    | 80                     | 92                    | 99                     | †                     | †                      | 0                     | 29.0                   | 0                     | 22                     | 0                     | 26                     | 3.1                   | 3.1                    | 4.8                        | 88.2                   | 90.7  |             |  |
| +3.2  | 5.8  | 5.3                    | 4                            | SP                 | SP                             | 28                     | 85                                | 82                     | 72                    | 76                     | 83                    | 90                     | †                     | †                      | 0                     | 29.0                   | 0                     | 23                     | 0                     | 29                     | 4.4                   | 5.0                    | 5.3                        | 91.1                   | 93.0  |             |  |
| +5.9  | 4.6  | 4.3                    | 3                            | SP                 | SP                             | 53                     | 146                               | 146                    | 136                   | 146                    | 198                   | 263                    | †                     | †                      | 0                     | 30.0                   | 0                     | 25                     | 0                     | 30                     | 5.5                   | 6.2                    | 5.8                        | 89.6                   | 98.3  |             |  |
| -5.6  | †    | †                      | ††                           | SP                 | SP                             | 53                     | 146                               | 146                    | 136                   | 146                    | 198                   | 263                    | †                     | †                      | 0                     | 30.0                   | 0                     | 25                     | 0                     | 30                     | 5.5                   | 6.2                    | 5.8                        | 89.6                   | 98.3  |             |  |
| <u>M5A1, 2-1/2-ton, 6x6 Cargo Truck</u>       |      |                        |                              |                    |                                |                        |                                   |                        |                       |                        |                       |                        |                       |                        |                       |                        |                       |                        |                       |                        |                       |                        |                            |                        |       |             |  |
| 0   | 6.3  | 6.2                    | 7                            | ML                 | CL-ML                          | 44                     | 74                                | 76                     | 60                    | 68                     | 93                    | 96                     | 23                    | 40                     | 1.7                   | 27.0                   | 0                     | 19                     | 1.3                   | 16                     | 56.4                  | 30.0                   | 23.2                       | 84.6                   | 98.6  |             |  |
| 0   | 8.3  | 7.8                    | 0                            | ML                 | CL-ML                          | 76                     | 137                               | 119                    | 82                    | 88                     | 96                    | 100                    | 40                    | 37                     | 0                     | 35.0                   | 0                     | 25                     | 0.9                   | 30                     | 43.2                  | 30.5                   | 27.3                       | 78.7                   | 84.4  |             |  |
| 0   | 15.9 | 15.8                   | 0                            | ML                 | CL-ML                          | 41                     | 81                                | 85                     | 73                    | 76                     | 77                    | 82                     | 29                    | 26                     | 3.0                   | 25.0                   | 0                     | 19                     | 1.0                   | 15                     | 50.9                  | 36.9                   | 25.8                       | 77.3                   | 91.0  |             |  |
| 0   | 13.5 | 13.0                   | 0                            | ML                 | CL-ML                          | 39                     | 84                                | 85                     | 70                    | 70                     | 72                    | 78                     | 31                    | 29                     | 3.0                   | 26.0                   | 0                     | 19                     | 0.9                   | 14                     | 51.7                  | 35.2                   | 25.5                       | 79.9                   | 92.9  |             |  |
| +9.6  | 4.3  | 4.1                    | 1                            | SP                 | SP                             | 33                     | 94                                | 78                     | 74                    | 76                     | 79                    | 87                     | †                     | †                      | 0.7                   | 23.0                   | 0                     | 21                     | 0                     | 35                     | 3.9                   | 5.4                    | 5.5                        | 90.1                   | 94.1  |             |  |
| -8.5  | 2.3  | 2.2                    | 0                            | SP                 | SP                             | 40                     | 96                                | 93                     | 92                    | 88                     | 92                    | 96                     | †                     | †                      | 0                     | 24.0                   | 0                     | 26                     | 0                     | 28                     | 1.6                   | 3.9                    | 3.9                        | 85.6                   | 90.5  |             |  |
| -10.3   | 13.2 | 12.9                   | 0                            | SP                 | SP                             | 55                     | 173                               | 289                    | 374                   | 380                    | 377                   | 349                    | †                     | †                      | 0                     | 25.0                   | 0                     | 20                     | 0                     | 26                     | 1.5                   | 2.9                    | 1.3                        | 92.6                   | 101.2 |             |  |
| +9.1  | 4.6  | 4.5                    | 6                            | SP                 | SP                             | 26                     | 87                                | 76                     | 80                    | 80                     | 78                    | 75                     | †                     | †                      | 0                     | 29.0                   | 0                     | 26                     | 0                     | 27                     | 2.4                   | 2.9                    | 3.4                        | 88.8                   | 91.8  |             |  |
| +2.8  | 7.4  | 7.1                    | 3                            | SP                 | SP                             | 40                     | 130                               | 182                    | 227                   | 234                    | 227                   | 212                    | †                     | †                      | 0                     | 27.0                   | 0                     | 23                     | 0                     | 26                     | 2.0                   | 2.9                    | 3.4                        | 90.7                   | 94.5  |             |  |
| +2.2  | 12.6 | 12.4                   | 5                            | SP                 | SP                             | 32                     | 42                                | 87                     | 108                   | 115                    | 114                   | 123                    | †                     | †                      | 0.3                   | 25.0                   | 0                     | 22                     | 0                     | 28                     | 2.8                   | 7.2                    | 5.2                        | 87.6                   | 97.0  |             |  |
| -4.9  | 8.3  | 7.9                    | 0                            | SP                 | SP                             | 32                     | 42                                | 87                     | 108                   | 115                    | 114                   | 123                    | †                     | †                      | 0.3                   | 25.0                   | 0                     | 22                     | 0                     | 28                     | 2.8                   | 7.3                    | 5.3                        | 87.6                   | 97.0  |             |  |
| +7.4  | 8.1  | 8.0                    | 4                            | SP                 | SP                             | 32                     | 99                                | 128                    | 116                   | 109                    | 115                   | 125                    | †                     | †                      | 1.7                   | 23.0                   | 0                     | 25                     | 0                     | 24                     | 1.1                   | 3.7                    | 4.8                        | 88.7                   | 92.9  |             |  |
| +0.6  | 6.9  | 6.8                    | 4                            | SP                 | SP                             | 32                     | 99                                | 128                    | 116                   | 109                    | 115                   | 125                    | †                     | †                      | 1.7                   | 23.0                   | 0                     | 25                     | 0                     | 24                     | 1.7                   | 3.7                    | 4.8                        | 88.7                   | 92.9  |             |  |

Table B2 (Concluded)

| No.                                     | Test  |          | Straight-Line Distance (D <sub>s</sub> )<br>ft | Actual Path Length (D <sub>p</sub> )<br>ft | Path Elongation Ratio (D <sub>p</sub> /D <sub>s</sub> ) | Total Time (t)<br>sec | Mean Vegetation Structural Cell Diam (D <sub>c</sub> )<br>ft |                    | Mean Obstacle Spacing (S <sub>o</sub> )<br>ft | Percent Area Denied (A <sub>d</sub> ) | Slope % | Actual Speed mph | Speed Made Good mph | Wheel Slip % | Unified Soil Classification |     | Average Cone Ind |     |     |  |
|---|-------|----------|--|--|---|-----------------------|--|--------------------|---|---------------------------------------|---------|------------------|---------------------|--------------|-----------------------------|-----|------------------|-----|-----|--|
|   | Site  | Date     |  |  |   |                       | 0- to 6-in. Layer  | 6- to 12-in. Layer |   |                                       |         |                  |                     |              | 0                           | 3   | 6                | 9   |     |  |
|   |       |          |  |  |   |                       |  |                    |   |                                       |         |                  |                     |              |                             |     |                  |     |     |  |
| M59C, Amphibious Cargo Carrier (Weasel) |       |          |  |  |   |                       |  |                    |   |                                       |         |                  |                     |              |                             |     |                  |     |     |  |
| 4                                       | NASA1 | 7/31/64  | 612  | 618  | 1.01  | 27.5                  | 103  | 23.1               | 7   | 0                                     | 15.3    | 15.2             | 0                   | ML           | CL-ML                       | 51  | 93               | 100 | 92  |  |
| 5                                       | NASA1 | 7/31/64  | 598  | 560  | 1.00  | 27.5                  | 107  | 24.0               | 7   | 0                                     | 13.9    | 13.8             | 0                   | ML           | CL-ML                       | 39  | 80               | 81  | 82  |  |
| 6                                       | NASA2 | 8/3/64   | 405  | 408  | 1.01  | 23.4                  | 59   | 13.2               | 23  | 0                                     | 6.4     | 6.4              | 0                   | ML           | CL-ML                       | 112 | 196              | 201 | 200 |  |
| 7                                       | NASA2 | 8/3/64   | 453  | 483  | 1.07  | 40.0                  | 61   | 13.7               | 21  | 0                                     | 8.2     | 7.7              | 0                   | ML           | CL-ML                       | 150 | 261              | 275 | 270 |  |
| 8A                                      | NASA2 | 8/1/64   | 240  | 316  | 1.08  | 23.8                  | 61   | 13.7               | 21  | 0                                     | 9.0     | 8.4              | 0                   | ML           | CL-ML                       | 48  | 95               | 78  | 69  |  |
| 14A                                     | NASA3 | 8/21/64  | 295  | †  | †   | †                     | 34   | 7.6                | 62  | 0                                     | 0.2     | 0.2              | 0                   | ML           | CL-ML                       | 135 | 183              | 191 | 144 |  |
| 15B                                     | NASA3 | 8/21/64  | 295  | †  | †   | †                     | 31   | 6.9                | 75  | 0                                     | 0       | 0                | 0                   | ML           | CL-ML                       | †   | †                | †   | †   |  |
| 19                                      | NASA4 | 9/10/64  | 562  | 570  | 1.01  | 34.9                  | 74   | 16.6               | 15  | 0                                     | 11.1    | 11.0             | 0                   | SM           | SM                          | 71  | 173              | 297 | 280 |  |
| 20                                      | NASA4 | 8/20/64  | 549  | 556  | 1.01  | 36.8                  | 72   | 16.1               | 16  | 0                                     | 10.3    | 10.2             | 0                   | SM           | SM                          | 74  | 169              | 224 | 246 |  |
| 301                                     | E1    | 4/11/65  | 150  | 153  | 1.02  | 13.9                  | 71   | 15.9               | 15  | +10.1                                 | 7.5     | 7.4              | ††                  | SP           | SP                          | 42  | 112              | 116 | 120 |  |
| 304                                     | E1    | 4/15/65  | 216  | 218  | 1.01  | 13.7                  | 63   | 14.1               | 19  | +0.6                                  | 10.9    | 10.7             | ††                  | SP           | SP                          | 32  | 94               | 93  | 101 |  |
| 305                                     | E1    | 4/15/65  | 196  | 200  | 1.02  | 13.7                  | 62   | 13.9               | 19  | -7.8                                  | 9.9     | 9.8              | ††                  | SP           | SP                          | 42  | 112              | 116 | 120 |  |
| 306                                     | E4    | 4/16/65  | 139  | 140  | 1.01  | 8.9                   | 65   | 14.6               | 17  | -2.7                                  | 10.7    | 10.6             | ††                  | SP           | SP                          | 29  | 75               | 87  | 98  |  |
| 307                                     | E4    | 4/16/65  | 214  | 218  | 1.02  | 13.3                  | 63   | 14.1               | 18  | -12.6                                 | 11.2    | 11.0             | ††                  | SP           | SP                          | 29  | 75               | 87  | 98  |  |
| 308                                     | E4    | 4/16/65  | 230  | 233  | 1.01  | 19.0                  | 63   | 14.1               | 18  | +12.6                                 | 8.4     | 8.3              | ††                  | SP           | SP                          | 29  | 75               | 87  | 98  |  |
| 309                                     | E4    | 4/16/65  | 214  | 218  | 1.02  | 13.4                  | 60   | 13.4               | 20  | -11.0                                 | 11.1    | 10.9             | ††                  | SP           | SP                          | 32  | 92               | 81  | 83  |  |
| 310                                     | E1    | 4/16/65  | 250  | 253  | 1.01  | 19.0                  | 67   | 15.0               | 16  | +12.0                                 | 9.1     | 9.0              | ††                  | SP           | SP                          | 32  | 92               | 81  | 83  |  |
| 311                                     | E3    | 4/16/65  | 287  | 294  | 1.02  | 27.3                  | 56   | 12.5               | 23  | +9.5                                  | 7.3     | 7.2              | ††                  | SP           | SP                          | 41  | 99               | 116 | 101 |  |
| 312                                     | E3    | 4/16/65  | 212  | 215  | 1.01  | 18.2                  | 48   | 10.8               | 31  | -5.6                                  | 8.0     | 7.9              | ††                  | SP           | SP                          | 41  | 99               | 116 | 101 |  |
| 313                                     | E3    | 4/16/65  | 136  | 136  | 1.00  | 9.1                   | 51   | 11.4               | 28  | -1.0                                  | 10.3    | 10.2             | ††                  | SP           | SP                          | 36  | 125              | 116 | 80  |  |
| 314                                     | E3    | 4/16/65  | 280  | 286  | 1.02  | 22.9                  | 58   | 13.0               | 22  | +9.6                                  | 8.5     | 8.3              | ††                  | SP           | SP                          | 36  | 125              | 116 | 80  |  |
| 315                                     | E3    | 4/16/65  | 124  | 137  | 1.10  | 16.1                  | 46   | 10.3               | 34  | -8.1                                  | 5.8     | 5.3              | ††                  | SP           | SP                          | 36  | 125              | 116 | 80  |  |
| 316                                     | E2    | 4/17/65  | 386  | 414  | 1.07  | 62.8                  | 49   | 11.0               | 33  | +7.2                                  | 4.5     | 4.2              | ††                  | SP           | SP                          | 76  | 155              | 130 | 113 |  |
| 317                                     | E2    | 4/17/65  | 299  | 308  | 1.03  | 45.2                  | 44   | 9.9                | 40  | -6.9                                  | 4.7     | 4.5              | ††                  | SP           | SP                          | 71  | 210              | 221 | 213 |  |
| 318                                     | E2    | 4/17/65  | 251  | 250  | 1.16  | 34.8                  | 44   | 9.9                | 40  | +7.5                                  | 5.7     | 4.9              | ††                  | SP           | SP                          | 76  | 155              | 130 | 113 |  |
| 319                                     | E2    | 4/17/65  | 86   | 86   | 1.00  | 9.0                   | 44   | 9.9                | 40  | -1.3                                  | 6.5     | 6.5              | ††                  | SP           | SP                          | 76  | 155              | 130 | 113 |  |
| M113, Armored Personnel Carrier (APC)   |       |          |  |  |   |                       |  |                    |   |                                       |         |                  |                     |              |                             |     |                  |     |     |  |
| 25                                      | NASA1 | 11/23/64 | 884  | 897  | 1.01  | 32.5                  | 167  | 37.4               | 6   | 0                                     | 18.8    | 18.5             | 0                   | ML           | CL-ML                       | 70  | 112              | 127 | 120 |  |
| 26                                      | NASA1 | 11/23/64 | 744  | 750  | 1.01  | 26.3                  | 183  | 41.0               | 5   | 0                                     | 19.4    | 19.3             | 0                   | ML           | CL-ML                       | 60  | 105              | 112 | 122 |  |
| 27                                      | NASA1 | 11/23/64 | 509  | 514  | 1.01  | 21.0                  | 159  | 35.6               | 7   | 0                                     | 16.7    | 16.5             | 0                   | ML           | CL-ML                       | 56  | 69               | 69  | 79  |  |
| 28                                      | NASA1 | 11/23/64 | 842  | 855  | 1.02  | 27.1                  | 166  | 37.2               | 6   | 0                                     | 21.5    | 21.2             | 0                   | ML           | CL-ML                       | 62  | 98               | 91  | 91  |  |
| 29                                      | NASA2 | 11/24/64 | 506  | 558  | 1.10  | 143.8                 | 68   | 15.2               | 39  | 0                                     | 2.6     | 2.4              | 0                   | ML           | CL-ML                       | 99  | 247              | 200 | 178 |  |
| 30                                      | NASA2 | 11/24/64 | 419  | 555  | 1.32  | 90.0                  | 61   | 13.7               | 48  | 0                                     | 3.9     | 2.9              | 0                   | ML           | CL-ML                       | 113 | 171              | 156 | 180 |  |
| 31                                      | NASA2 | 11/24/64 | 241  | 245  | 1.02  | 16.8                  | 70   | 15.7               | 37  | 0                                     | 9.9     | 9.8              | 0                   | ML           | CL-ML                       | †   | †                | †   | †   |  |
| 32                                      | NASA2 | 11/24/64 | 494  | 535  | 1.08  | 147.7                 | 58   | 13.0               | 54  | 0                                     | 2.5     | 2.3              | 0                   | ML           | CL-ML                       | 109 | 186              | 157 | 168 |  |
| 356                                     | NASA4 | 4/1/65   | 556  | 571  | 1.03  | 38.0                  | 78   | 17.5               | 30  | 0                                     | 10.3    | 10.0             | 0                   | SM           | SM                          | 25  | 71               | 91  | 101 |  |
| 357                                     | NASA4 | 4/1/65   | 606  | 635  | 1.05  | 52.3                  | 79   | 17.7               | 30  | 0                                     | 8.3     | 7.9              | 0                   | SM           | SM                          | 31  | 50               | 86  | 107 |  |
| 358                                     | E1    | 4/19/65  | 142  | 174  | 1.22  | 14.0                  | 60   | 15.5               | 36  | +0.9                                  | 8.5     | 6.9              | 0                   | SP           | SP                          | †   | †                | †   | †   |  |
| 359                                     | E1    | 4/19/65  | 162  | 180  | 1.11  | 13.8                  | 71   | 15.9               | 34  | -9.5                                  | 8.9     | 8.0              | 0                   | SP           | SP                          | 28  | 74               | 86  | 89  |  |
| 360                                     | E1    | 4/19/65  | 242  | 256  | 1.06  | 23.2                  | 80   | 17.9               | 27  | +8.5                                  | 7.5     | 7.1              | 4                   | SP           | SP                          | 28  | 66               | 72  | 66  |  |
| 361                                     | E1    | 4/20/65  | 145  | 148  | 1.02  | 13.8                  | 76   | 17.0               | 30  | +10.8                                 | 7.3     | 7.2              | 0                   | SP           | SP                          | 31  | 74               | 81  | 76  |  |
| 362                                     | E4    | 4/21/65  | 177  | 194  | 1.08  | 16.5                  | 67   | 15.0               | 37  | -2.2                                  | 8.0     | 7.4              | 0                   | SP           | SP                          | 32  | 70               | 80  | 62  |  |
| 363                                     | E4    | 4/21/65  | 191  | 203  | 1.06  | 14.0                  | 69   | 15.5               | 35  | -11.9                                 | 9.9     | 9.3              | 0                   | SP           | SP                          | 28  | 65               | 71  | 84  |  |
| 364                                     | E4    | 4/21/65  | 180  | 182  | 1.01  | 18.8                  | 73   | 16.4               | 31  | +11.9                                 | 6.6     | 6.5              | 2                   | SP           | SP                          | 32  | 70               | 80  | 62  |  |
| 365                                     | E4    | 4/21/65  | 212  | 236  | 1.11  | 13.1                  | 72   | 16.1               | 32  | -10.5                                 | 12.3    | 11.0             | 0                   | SP           | SP                          | 26  | 64               | 93  | 120 |  |
| 366                                     | E4    | 4/21/65  | 182  | 186  | 1.02  | 18.7                  | 69   | 15.5               | 35  | +12.6                                 | 6.8     | 6.6              | 1                   | SP           | SP                          | 32  | 70               | 80  | 62  |  |

† No measurement made.  
†† Instrumentation failure.

Table B2 (Concluded)

| Actual<br>Speed<br>mph                  |      | Speed<br>Made<br>Good<br>mph | Wheel<br>Slip<br>% | Unified Soil<br>Classification |     | Soils Data                       |                        |      |      |      |      |    |    |                   |                       |                        |                 |                 |                 |                 |                 |  |                       |                       |                        |                       |
|---|------|------------------------------|--------------------|--------------------------------|-----|----------------------------------|------------------------|------|------|------|------|----|----|-------------------|-----------------------|------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|--|-----------------------|-----------------------|------------------------|-----------------------|
|   |      |                              |                    |                                |     | Average Cone Index at Depth, in. |                        |      |      |      |      |    |    | Rating Cone Index |                       | Shearograph Data       |                 |                 |                 |                 |                 | Moisture Content<br>Percent of Dry Soil Weight |                       |                       | Dry Density<br>pcf     |                       |
|   |      |                              |                    |                                |     | 0- to 6-<br>in. Layer            | 6- to 12-<br>in. Layer | 0    | 3    | 6    | 9    | 12 | 15 | 18                | 0- to 6-<br>in. Layer | 6- to 12-<br>in. Layer | C <sub>rl</sub> | φ <sub>rl</sub> | C <sub>rs</sub> | φ <sub>rs</sub> | C <sub>ss</sub> | φ <sub>ss</sub>                                | 0- to 1-<br>in. Layer | 0- to 6-<br>in. Layer | 6- to 12-<br>in. Layer | 0- to 6-<br>in. Layer |
| M99, Amphibious Cargo Carrier (Wheeled) |      |                              |                    |                                |     |                                  |                        |      |      |      |      |    |    |                   |                       |                        |                 |                 |                 |                 |                 |  |                       |                       |                        |                       |
| 15.3                                    | 15.2 | 0                            | ML                 | CL-ML                          | 51  | 93                               | 100                    | 92   | 97   | 152  | 124  | 33 | 34 | 0                 | 41.0                  | 3.5                    | 27              | 2.0             | 14              | +               | 35.0            | 26.4   | 80.1                  | 90.1                  |                        |                       |
| 13.9                                    | 13.8 | 0                            | ML                 | CL-ML                          | 39  | 80                               | 81                     | 82   | 82   | 104  | 113  | 23 | 38 | +                 | +                     | +                      | +               | +               | +               | +               | 36.9            | 27.5   | 79.3                  | 89.5                  |                        |                       |
| 6.4                                     | 6.4  | 0                            | ML                 | CL-ML                          | 112 | 196                              | 201                    | 200  | 197  | 205  | 215  | 22 | 34 | +                 | 31.0                  | 0                      | 35              | 1.5             | 36              | +               | 24.0            | 86.5   | --                    | 98.2                  |                        |                       |
| 8.2                                     | 7.7  | 0                            | ML                 | CL-ML                          | 150 | 261                              | 275                    | 270+ | 274+ | 273+ | 282+ | +  | +  | 0.5               | 31.0                  | 0                      | 35              | 1.5             | 36              | +               | 23.1            | 19.7   | 85.2                  | 97.0                  |                        |                       |
| 9.0                                     | 8.4  | 0                            | ML                 | CL-ML                          | 48  | 95                               | 78                     | 69   | 118  | 109  | 116  | 29 | 41 | 1.2               | 43.5                  | 0.9                    | 33              | 1.8             | 38              | +               | 29.0            | 24.6   | 87.1                  | 95.7                  |                        |                       |
| 0.2                                     | 0.2  | 0                            | ML                 | CL-ML                          | 136 | 183                              | 191                    | 184  | 146  | +    | +    | +  | +  | +                 | +                     | +                      | +               | +               | +               | +               | 23.5            | 20.0   | 85.3                  | 100.0                 |                        |                       |
| 0                                       | 0    | 0                            | ML                 | CL-ML                          | +   | +                                | +                      | +    | +    | +    | +    | +  | +  | +                 | +                     | +                      | +               | +               | +               | +               | +               | +  | +                     | +                     |                        |                       |
| 11.1                                    | 11.0 | 0                            | SM                 | SM                             | 71  | 173                              | 297                    | 280  | 279  | 285  | 282  | +  | +  | 1.0               | 38.0                  | 1.6                    | 27              | 3.4             | 32              | -               | 16.9            | 15.0   | 88.9                  | 95.5                  |                        |                       |
| 10.3                                    | 10.2 | 0                            | SM                 | SM                             | 74  | 169                              | 224                    | 246  | 241  | 270  | 272  | +  | +  | 1.0               | 36.5                  | 1.2                    | 41              | 1.1             | 47              | --              | 21.1            | 19.3   | 87.9                  | 95.9                  |                        |                       |
| 7.5                                     | 7.4  | +                            | SP                 | SP                             | 42  | 112                              | 116                    | 120  | 160  | 231  | 283  | +  | +  | 0                 | 32.0                  | 0                      | 26              | 0               | 31              | 33.9            | 20.9            | 12.6   | 85.7                  | 98.2                  |                        |                       |
| 10.9                                    | 10.7 | +                            | SP                 | SP                             | 32  | 94                               | 93                     | 101  | 105  | 103  | 105  | +  | +  | 0                 | 30.0                  | 0                      | 26              | 0               | 29              | 6.1             | 6.0             | 4.4  | 92.6                  | 98.0                  |                        |                       |
| 9.9                                     | 9.5  | +                            | SP                 | SP                             | 42  | 112                              | 116                    | 120  | 160  | 231  | 283  | +  | +  | 0                 | 32.0                  | 0                      | 26              | 0               | 31              | 33.9            | 20.9            | 12.6   | 85.7                  | 98.2                  |                        |                       |
| 10.7                                    | 10.6 | +                            | SP                 | SP                             | 29  | 75                               | 87                     | 98   | 99   | 105  | 107  | +  | +  | 0                 | 20.0                  | 0                      | 22              | 0               | 27              | 2.8             | 4.4             | 1.6  | 93.8                  | 97.1                  |                        |                       |
| 11.2                                    | 11.0 | +                            | SP                 | SP                             | 29  | 75                               | 87                     | 98   | 99   | 105  | 107  | +  | +  | 0                 | 20.0                  | 0                      | 22              | 0               | 27              | 2.8             | 4.4             | 1.6  | 93.8                  | 97.1                  |                        |                       |
| 8.4                                     | 8.3  | +                            | SP                 | SP                             | 29  | 75                               | 87                     | 98   | 99   | 105  | 107  | +  | +  | 0                 | 20.0                  | 0                      | 22              | 0               | 27              | 2.8             | 4.4             | 1.6  | 93.8                  | 97.1                  |                        |                       |
| 11.1                                    | 10.9 | +                            | SP                 | SP                             | 32  | 92                               | 81                     | 83   | 82   | 83   | 89   | +  | +  | 0                 | 26.0                  | 0                      | 21              | 0               | 26              | 4.5             | 3.9             | 3.6  | 89.0                  | 94.0                  |                        |                       |
| 9.1                                     | 9.0  | +                            | SP                 | SP                             | 32  | 92                               | 81                     | 83   | 82   | 81   | 89   | +  | +  | 0                 | 26.0                  | 0                      | 21              | 0               | 26              | 4.5             | 3.9             | 3.6  | 89.0                  | 94.0                  |                        |                       |
| 7.3                                     | 7.2  | +                            | SP                 | SP                             | 41  | 99                               | 116                    | 101  | 101  | 94   | 100  | +  | +  | 1.0               | 23.0                  | 0                      | 19              | 0               | 30              | 0.9             | 2.1             | 3.2  | 93.6                  | 96.6                  |                        |                       |
| 8.0                                     | 7.9  | +                            | SP                 | SP                             | 41  | 99                               | 116                    | 101  | 101  | 94   | 100  | +  | +  | 1.0               | 23.0                  | 0                      | 19              | 0               | 30              | 0.9             | 2.1             | 3.2  | 93.6                  | 96.6                  |                        |                       |
| 10.3                                    | 10.2 | +                            | SP                 | SP                             | 36  | 125                              | 116                    | 80   | 89   | 100  | 100  | +  | +  | 0                 | 26.0                  | 0                      | 28              | 0               | 34              | 6.0             | 3.8             | 4.5  | 90.7                  | 93.6                  |                        |                       |
| 8.5                                     | 8.3  | +                            | SP                 | SP                             | 36  | 125                              | 116                    | 80   | 89   | 100  | 100  | +  | +  | 0                 | 26.0                  | 0                      | 28              | 0               | 34              | 6.0             | 3.8             | 4.5  | 90.7                  | 93.6                  |                        |                       |
| 5.8                                     | 5.3  | +                            | SP                 | SP                             | 36  | 125                              | 116                    | 80   | 89   | 100  | 100  | +  | +  | 0                 | 26.0                  | 0                      | 28              | 0               | 34              | 6.0             | 3.8             | 4.5  | 90.7                  | 93.6                  |                        |                       |
| 4.5                                     | 4.2  | +                            | SP                 | SP                             | 76  | 155                              | 130                    | 113  | 116  | 162  | 254  | +  | +  | 0                 | 22.0                  | 0                      | 24              | 0               | 31              | 3.7             | 7.4             | 8.3  | 80.5                  | 93.5                  |                        |                       |
| 4.7                                     | 4.5  | +                            | SP                 | SP                             | 71  | 210                              | 221                    | 213  | 238  | 413  | 468  | +  | +  | 0                 | 30.0                  | 0                      | 25              | 0               | 34              | 3.4             | 8.1             | 8.4  | 84.3                  | 97.9                  |                        |                       |
| 5.7                                     | 4.9  | +                            | SP                 | SP                             | 76  | 155                              | 130                    | 113  | 116  | 162  | 254  | +  | +  | 0                 | 22.0                  | 0                      | 24              | 0               | 31              | 3.7             | 7.4             | 8.3  | 80.5                  | 93.5                  |                        |                       |
| 6.5                                     | 6.5  | +                            | SP                 | SP                             | 76  | 155                              | 130                    | 113  | 116  | 162  | 254  | +  | +  | 0                 | 22.0                  | 0                      | 24              | 0               | 31              | 3.7             | 7.4             | 8.3  | 80.5                  | 93.5                  |                        |                       |
| M113, Armored Personnel Carrier (APC)   |      |                              |                    |                                |     |                                  |                        |      |      |      |      |    |    |                   |                       |                        |                 |                 |                 |                 |                 |  |                       |                       |                        |                       |
| 18.6                                    | 18.5 | 0                            | ML                 | CL-ML                          | 70  | 112                              | 127                    | 120  | 133  | 155  | 166  | +  | +  | +                 | +                     | +                      | +               | +               | +               | +               | 31.6            | 23.5   | 80.7                  | 92.9                  |                        |                       |
| 19.4                                    | 19.3 | 0                            | ML                 | CL-ML                          | 60  | 105                              | 112                    | 122  | 133  | 144  | 151  | +  | +  | +                 | +                     | +                      | +               | +               | +               | +               | 33.9            | 25.1   | 78.9                  | 91.0                  |                        |                       |
| 16.7                                    | 16.5 | 0                            | ML                 | CL-ML                          | 56  | 69                               | 69                     | 79   | 94   | 111  | 126  | +  | +  | +                 | +                     | +                      | +               | +               | +               | +               | 34.1            | 24.4   | 81.8                  | 93.9                  |                        |                       |
| 21.5                                    | 21.2 | 0                            | ML                 | CL-ML                          | 62  | 98                               | 91                     | 91   | 99   | 123  | 144  | +  | +  | +                 | +                     | +                      | +               | +               | +               | +               | 31.6            | 23.1   | 81.3                  | 93.4                  |                        |                       |
| 2.6                                     | 2.4  | 0                            | ML                 | CL-ML                          | 99  | 247                              | 200                    | 178  | 231  | 213  | 245  | +  | +  | +                 | +                     | +                      | +               | +               | +               | +               | 20.9            | 20.0   | 87.6                  | 98.0                  |                        |                       |
| 3.9                                     | 2.9  | 0                            | ML                 | CL-ML                          | 113 | 171                              | 156                    | 180  | 208  | 227  | 233  | +  | +  | +                 | +                     | +                      | +               | +               | +               | +               | 23.6            | 19.3   | 86.8                  | 99.1                  |                        |                       |
| 9.9                                     | 9.8  | 0                            | ML                 | CL-ML                          | +   | +                                | +                      | +    | +    | +    | +    | +  | +  | +                 | +                     | +                      | +               | +               | +               | +               | +               | +  | +                     | +                     |                        |                       |
| 2.5                                     | 2.2  | 0                            | ML                 | CL-ML                          | 109 | 186                              | 157                    | 168  | 208  | 218  | 247  | +  | +  | +                 | +                     | +                      | +               | +               | +               | +               | 22.6            | 21.0   | 87.6                  | 98.0                  |                        |                       |
| 10.2                                    | 10.0 | 0                            | SM                 | SM                             | 25  | 72                               | 91                     | 101  | 102  | 111  | 119  | 11 | 16 | +                 | +                     | +                      | +               | +               | +               | 47.4            | 27.6            | 17.4   | 88.8                  | 104.1                 |                        |                       |
| 8.3                                     | 7.9  | 0                            | SM                 | SM                             | 31  | 60                               | 86                     | 107  | 108  | 128  | 144  | 9  | 17 | +                 | +                     | +                      | +               | +               | +               | 46.4            | 25.5            | 17.6   | 89.6                  | 102.7                 |                        |                       |
| 8.5                                     | 6.9  | 0                            | SP                 | SP                             | +   | +                                | +                      | +    | +    | +    | +    | +  | +  | +                 | +                     | +                      | +               | +               | +               | +               | +               | +  | +                     | +                     |                        |                       |
| 8.9                                     | 8.0  | 0                            | SP                 | SP                             | 28  | 74                               | 86                     | 89   | 90   | 95   | 99   | +  | +  | 0                 | 26.0                  | 0                      | 25              | 0               | 26              | 8.1             | 9.1             | 7.6  | 87.9                  | 97.3                  |                        |                       |
| 7.5                                     | 7.1  | 4                            | SP                 | SP                             | 28  | 66                               | 72                     | 66   | 72   | 79   | 87   | +  | +  | 0                 | 35.0                  | 0                      | 24              | 0               | 28              | 8.5             | 3.5             | 8.8  | 86.0                  | 89.3                  |                        |                       |
| 7.3                                     | 7.2  | 0                            | SP                 | SP                             | 31  | 74                               | 81                     | 76   | 86   | 102  | 120  | +  | +  | 0.7               | 30.0                  | 0                      | 24              | 0               | 26              | 7.3             | 9.1             | 10.1   | 89.6                  | 85.4                  |                        |                       |
| 8.0                                     | 7.4  | 0                            | SP                 | SP                             | 32  | 70                               | 80                     | 62   | 77   | 70   | 82   | +  | +  | 0                 | 25.0                  | 0                      | 26              | 0               | 26              | 8.7             | 5.9             | 3.7  | 87.1                  | 94.1                  |                        |                       |
| 9.9                                     | 9.3  | 0                            | SP                 | SP                             | 28  | 65                               | 71                     | 84   | 105  | 98   | 119  | +  | +  | 0                 | 25.0                  | 0                      | 23              | 0               | 21              | 1.9             | 3.1             | 6.4  | 88.3                  | 90.1                  |                        |                       |
| 6.6                                     | 6.5  | 2                            | SP                 | SP                             | 32  | 70                               | 80                     | 62   | 77   | 70   | 82   | +  | +  | 0                 | 25.0                  | 0                      | 26              | 0               | 26              | 6.7             | 5.9             | 3.7  | 87.1                  | 94.1                  |                        |                       |
| 12.3                                    | 11.0 | 0                            | SP                 | SP                             | 26  | 64                               | 93                     | 120  | 173  | 130  | 185  | +  | +  | 0                 | 29.0                  | 0                      | 24              | 0               | 23              | 5.5             | 5.9             | 3.9  | 91.8                  | 94.4                  |                        |                       |
| 6.8                                     | 6.6  | 1                            | SP                 | SP                             | 32  | 70                               | 80                     | 62   | 77   | 70   | 82   | +  | +  | 0                 | 25.0                  | 0                      | 26              | 0               | 26              | 8.7             | 5.9             | 3.7  | 87.1                  | 94.1                  |                        |                       |

B

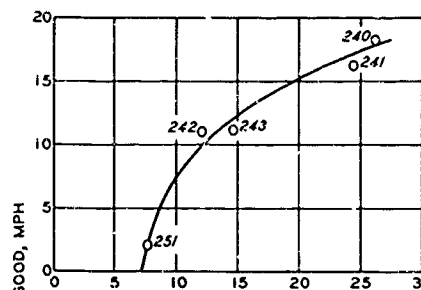


FIG. 1. M151

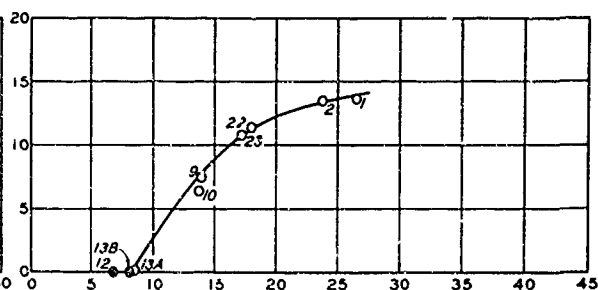


FIG. 2. M37

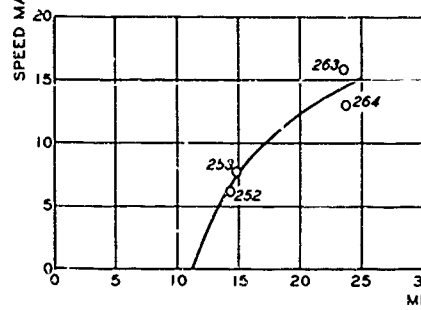


FIG. 3. M35A1

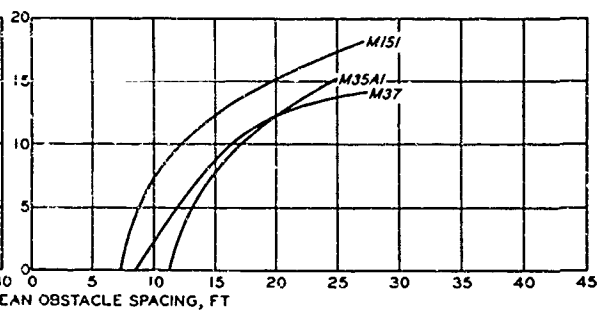


FIG. 4. SUMMARY

a. WHEELED VEHICLES

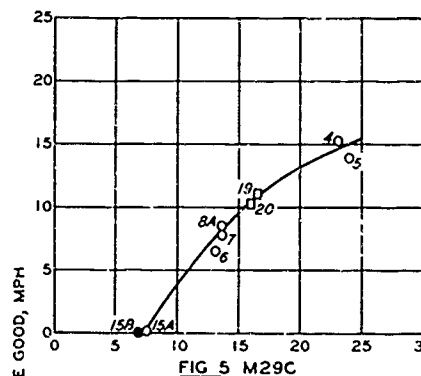


FIG. 5. M29C

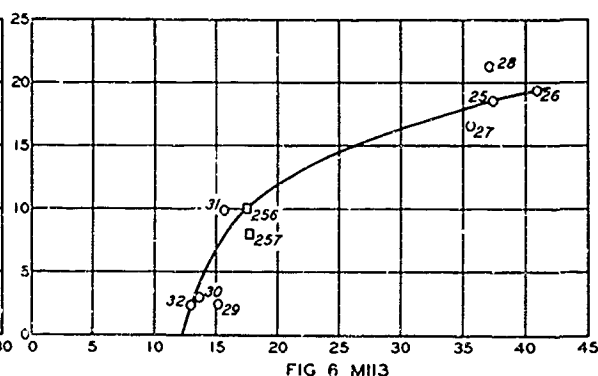


FIG. 6. M113

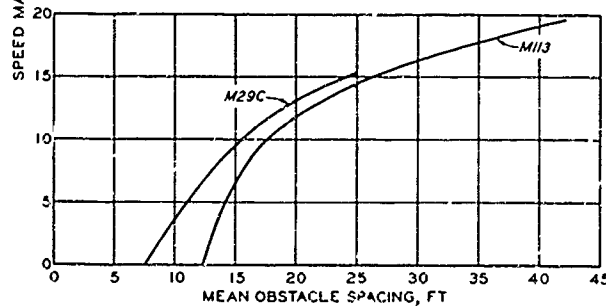


FIG. 7. SUMMARY

b. TRACKED VEHICLES

| LEGEND           |                   |
|------------------|-------------------|
| SOIL TYPE        |                   |
| 0- TO 6-IN LAYER | 6- TO 12-IN LAYER |
| ML               | CL-ML             |
| SM               | SM                |

NOTE NUMBERS NEAR PLOTTED POINTS INDICATE TEST NUMBERS  
CLOSED SYMBOLS DENOTE IMMOBILIZATIONS

**SPEED - SPACING RELATIONS**  
SPEED MADE GOOD VS  
MEAN OBSTACLE SPACING  
TESTS ON FINE-GRAINED SOILS AND SANDS  
WITH FINES, POORLY DRAINED  
NEARLY LEVEL SURFACES

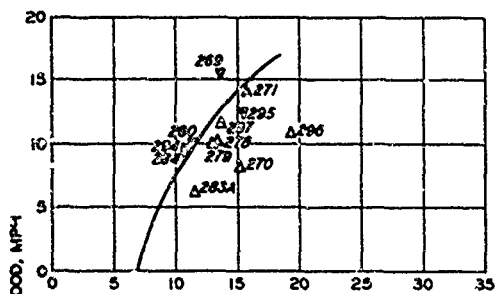


FIG. 1. M151

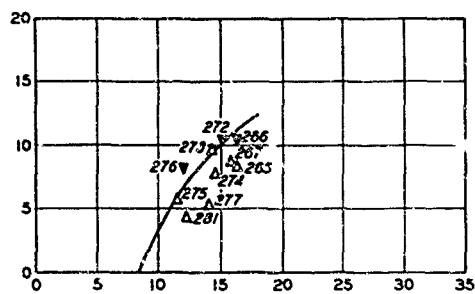


FIG. 2. M37

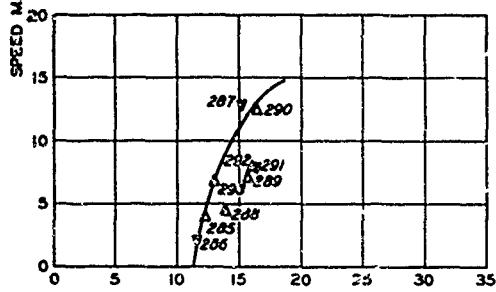
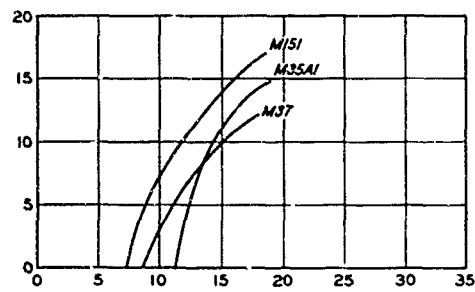


FIG. 3. M35A1



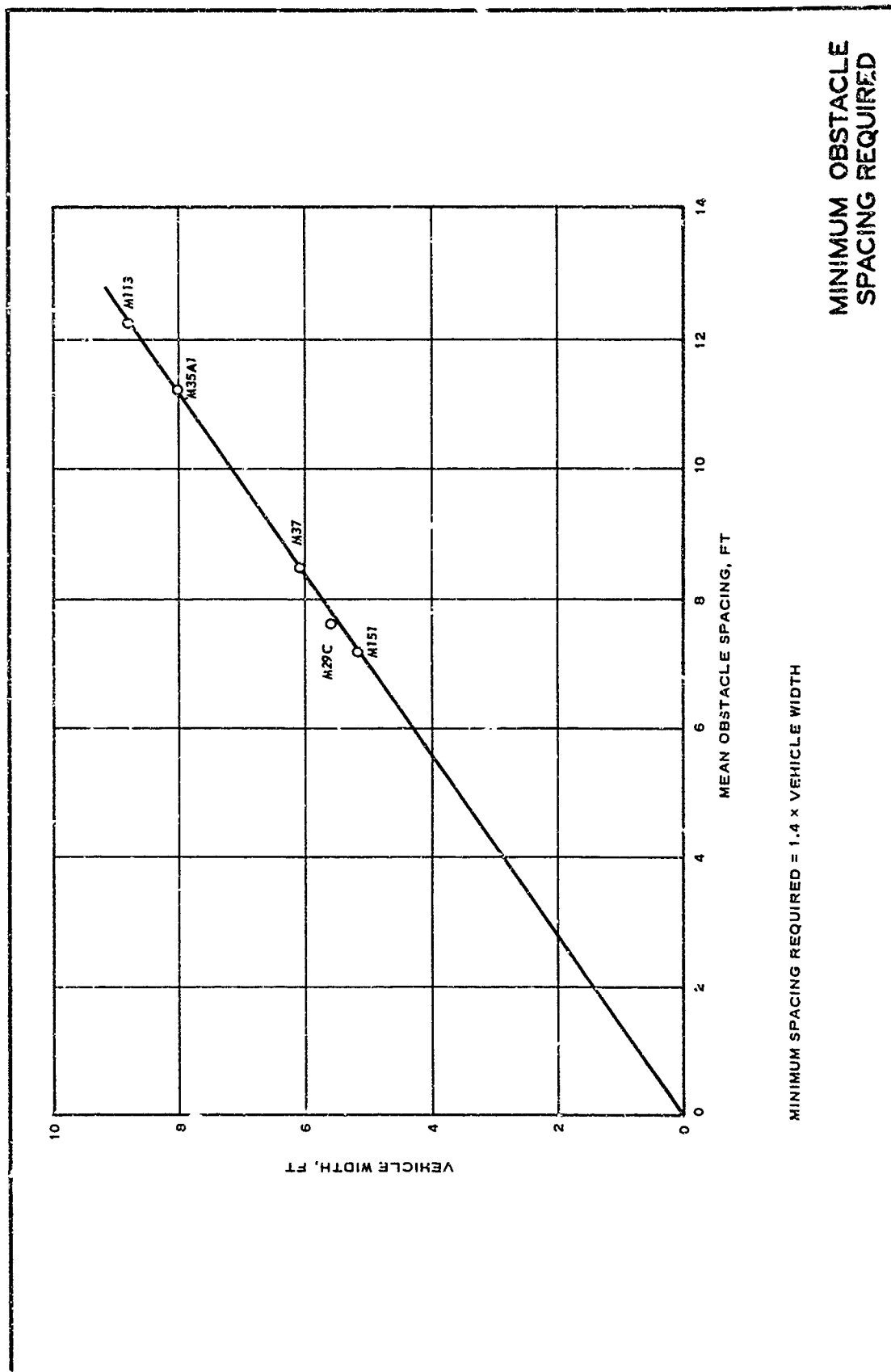


PLATE B3

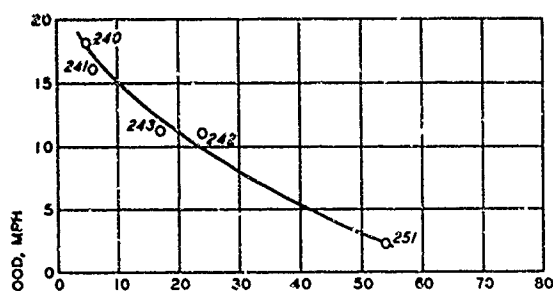


FIG. 1 M151

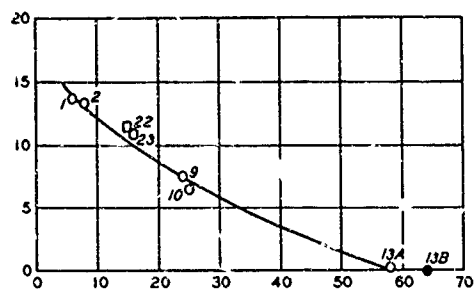


FIG. 2 M37

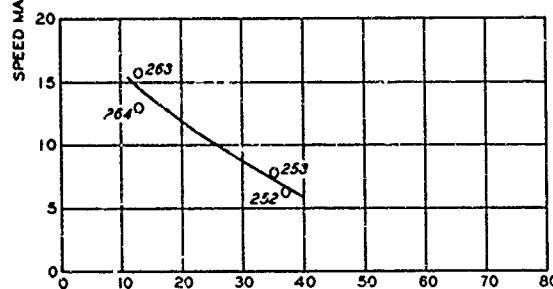


FIG. 3 M35A1

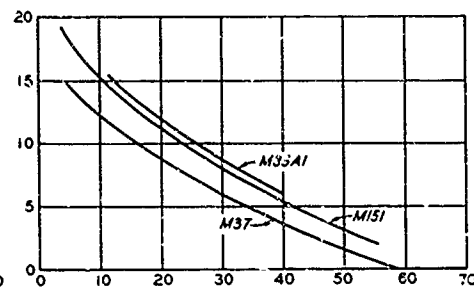


FIG. 4 SUMMARY

**a. WHEELED VEHICLES**

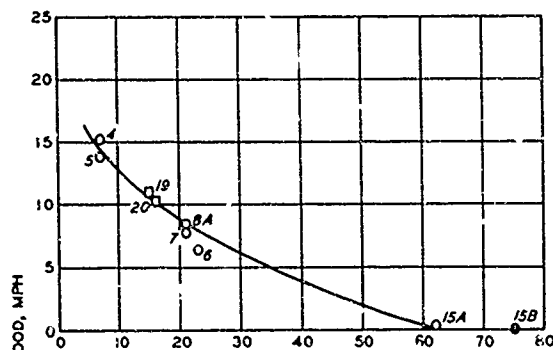


FIG. 5 M29C

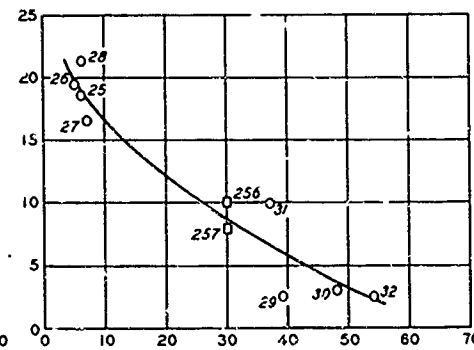


FIG. 6 M113

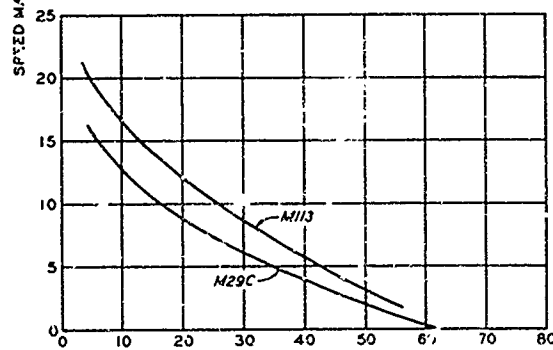


FIG. 7 SUMMARY

**b. TRACKED VEHICLES**

| LEGEND           |                   |
|------------------|-------------------|
| SOIL TYPE        |                   |
| 0- TO 8-IN LAYER | 6- TO 12-IN LAYER |
| O ML             | CL-ML             |
| Q SM             | SM                |

NOTE: NUMBERS NEAR PLOTTED POINTS INDICATE TEST NUMBERS  
CLOSED SYMBOLS DENOTE IMMOBILIZATIONS

**SPEED-AREA DENIED RELATIONS**  
SPEED MADE GOOD VS  
PERCENT AREA DENIED  
TESTS ON FINE-GRAINED SOILS AND SANDS  
WITH FINES, POORLY DRAINED  
NEARLY LEVEL SURFACES

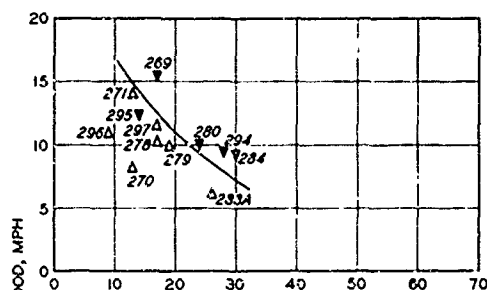


FIG. 1. M15J

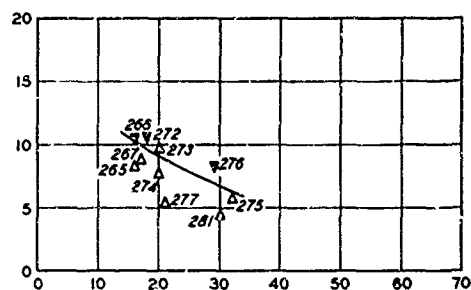


FIG. 2. M37

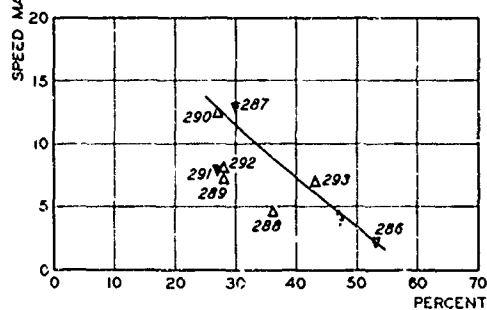


FIG. 3. M35AI

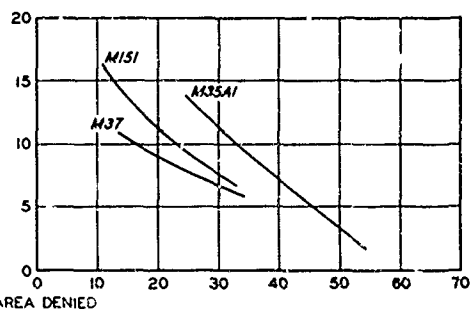


FIG. 4. SUMMARY

#### a. WHEELED VEHICLES

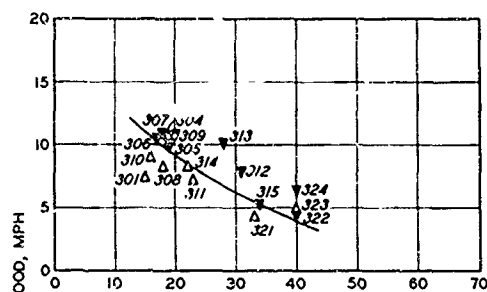


FIG. 5. M29C

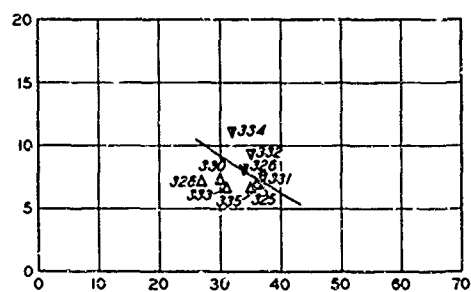


FIG. 6. M113

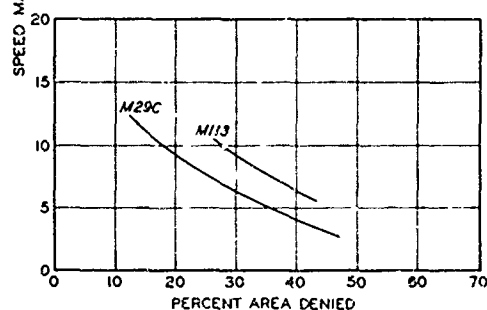


FIG. 7. SUMMARY

#### b. TRACKED VEHICLES

#### LEGEND

SOIL TYPE, SP

Δ UPSLOPE

▽ DOWNSLOPE

NOTE: NUMBERS NEAR PLOTTED POINTS INDICATE TEST NUMBERS

**SPEED-AREA  
DENIED RELATIONS**  
SPEED MADE GOOD VS  
PERCENT AREA DENIED  
TESTS ON COARSE-GRAINED SOILS  
SLOPING SURFACES



Unclassified

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| 4. DESCRIPTIVE NOTES (Type of report and inclusive dates)<br>Appendix B, Volume I, to final report  |                              |   |
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| 13. ABSTRACT<br>A total of 95 lateral obstacle tests were conducted with two tracked and three wheeled vehicles at the NASA Marshall Space Flight Center, Miss., and Eglin Air Force Base, Fla. The principal conclusions from these tests were that (a) vehicle performance in terms of speed made good in an array of vegetation assemblages can be correlated with the density of vegetation assemblages expressed as mean obstacle spacing, (b) the minimum obstacle spacing required to permit movement of a vehicle can be computed from vehicle width, and (c) the speed made good a vehicle can achieve when maneuvering in lateral obstacles is significantly affected by the slope of the terrain. Methods of determining mean obstacle spacing from structural cell diameter and percent area denied from stem diameters of trees, vehicle width, and structural cell diameter are shown. A method of determining percent area denied by logs, mounds, and other obstacles is suggested. |                              |   |

DD FORM 1473

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~~Security Classification~~

| 14 | KEY WORDS           | LINK A |    | LINK B |    | LINK C |    |
|----|---------------------|--------|----|--------|----|--------|----|
|    |                     | ROLE   | WT | ROLE   | WT | ROLE   | WT |
|    | Barriers            |        |    |        |    |        |    |
|    | Cross-country tests |        |    |        |    |        |    |
|    | Mathematical models |        |    |        |    |        |    |
|    | Military vehicles   |        |    |        |    |        |    |
|    | Terrain             |        |    |        |    |        |    |
|    | Vegetation          |        |    |        |    |        |    |

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